European
Commission

GENDERED INNOVATIONS 2:
How Inclusive Analysis Contributes to Research and Innovation

Policy Review

Gendered Innovations 2:

How Inclusive Analysis Contributes to Research and Innovation

H2020 Expert Group to update and expand
"Gendered Innovations/ Innovation through Gender"
Chairperson: Londa Schiebinger
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FOREWORD

The COVID-19 outbreak in 2020 has caused a major disruption in our global system. In many ways, the pandemic and the political measures taken to contain the spread of the virus have revealed gender inequalities and the importance of investigating sex and gender differences.

While worldwide statistics suggest similar infection rates for men and women, a significantly higher proportion of men than women succumb to the disease across groups of similar age, and an increasing body of research is putting forward biological differences between the sexes, in particular relating to immune responses. At the same time, women are more exposed to the virus due to their disproportionate representation among healthcare workers. They are also being more severely affected than men by the economic and social consequences of the pandemic, due to their overwhelming role as care and education providers within households and their larger proportion among non-salaried, self-employed, part-time and precarious employees. Furthermore, they have fallen victim to a surge in gender-based and domestic violence, observed across the EU and worldwide.

This report includes a recent case study on the impact of sex and gender in the COVID-19 pandemic, detailing findings that can inform a post-pandemic recovery strategy that is truly inclusive and leaves no one behind.

Taking into account the gender dimension – that is, ensuring that the biological characteristics as well as the social and cultural features, behaviours and needs of both women and men are taken into consideration – is vital for the societal relevance and quality of research and innovation (R & I). Integrating sex and gender-based analysis into R & I, and adopting an inclusive approach which also considers intersecting social categories such as ethnicity, age or disability, is a matter of producing excellent research to the benefit of all European citizens.

This policy report provides methodological tools and concrete case studies to researchers and innovators, showcasing projects funded under Horizon 2020 and illustrating a successful gender integration into key R & I areas, including health, artificial intelligence and robotics, energy, transport, marine science and climate change, urban planning, agriculture, fair taxation and venture funding. The report also offers specific policy recommendations for effective implementation in Horizon Europe, highlighting the strategic objectives set out for the different Clusters, Missions and partnerships.

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As the EU Commissioner for Innovation, Research, Culture, Education and Youth, and holding gender equality matters very close to my heart, I am determined to step up our efforts to make sure that the integration of the gender dimension into R & I content is a cornerstone of Horizon Europe, and that it is fully acknowledged in the European Research Area (ERA). It is indeed crucial that EU Member States make sure that their national R & I programmes also take account of this dimension. In this way, together, we can take great strides towards a new, inclusive, and transformative ERA.

This report proves that effective action can be taken and embedded in R & I-funding programmes. I highly commend it and wish for it to be widely used and disseminated.

Mariya GABRIEL

Commissioner for Innovation, Research, Culture, Education and Youth

EXECUTIVE SUMMARY

The European Commission has become a global leader in setting policy for the integration of the gender dimension into research, as well as the implementation of these policies. Under the Horizon 2020 framework programme, applicants were asked to integrate, where relevant, sex and gender analysis into research content. Call topics for which this integration was considered mandatory were gender-flagged for easy identification.

Despite these efforts, there is still room for improvement, not only in Europe, but worldwide, as findings from the She Figures 2018 report show[1]. The interim evaluation of Horizon 2020 found that fewer funded research proposals than expected incorporated sex and gender analysis; it correlated this to the lack of knowledge about how to effectively consider a gender perspective and conduct gender and sex analysis, in addition to the 'absence of training on gender issues'[2].

To address this, the European Commission convened an expert group to support the integration of the gender dimension into EU research and innovation under the next framework programme, Horizon Europe. In 2011 the European Commission created the Gendered Innovations / Innovation through Gender Expert Group, which produced the report entitled Gendered Innovations: How gender analysis contributes to research, published by the Commission in 2013[3]. This new expert group updated and expanded the work.

Integrating sex and gender analysis into research and innovation (R & I) adds value to research and is therefore crucial to secure Europe's leadership in science and technology, and to support its inclusive growth.

The strengthening of the integration of the gender dimension into R & I is one of the gender equality priorities set for Horizon Europe. The gender dimension cuts across all aspects of Horizon Europe and contributes to numerous steps in the R & I cycle, ranging from disclosing the sex of cells in experiments to considering the needs of women, men and gender-diverse individuals as end-users of technological innovations.

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[1] Directorate-General for Research and Innovation (2019), *She Figures 2018*, European Commission (https://ec.europa.eu/info/publications/she-figures-2018_en).

[2] Directorate-General for Research and Innovation (2017), *Interim Evaluation: Gender equality as a crosscutting issue in Horizon 2020*, European Commission (https://ec.europa.eu/research/swafs/pdf/pub_gender_equality/interim_evaluation_gender_long_final.pdf), p. 26.

[3] Directorate-General for Research and Innovation (2013), *Gendered Innovations: How gender analysis contributes to research*, European Commission (https://op.europa.eu/en/publication-detail/-/publication/d15a85d6-cd2d-4fbc-b998-42e53a73a449/language-en/format-PDF/source-139651854).

Integrating sex and/or gender analysis into research and innovation:

▶ adds value to research in terms of excellence, creativity and business opportunities;

▶ helps researchers and innovators question gender norms and stereotypes, and rethink standards and reference models;

▶ leads to an in-depth understanding of diverse gender needs, behaviours and attitudes;

▶ addresses the diverse needs of citizens of the European Union and thereby enhances the societal relevance of the knowledge, technologies and innovations produced;

▶ contributes to the production of goods and services better suited to new markets.

This policy report presents the output of the work carried out by the Gendered Innovations 2 Expert Group. The case studies, terms, methods and policy recommendations presented here address the global challenges, targeted impacts and key R & I orientations of the six clusters of Horizon Europe's Pillar II, as well as mission areas and foreseen European partnerships.

These materials also provide guidance for future Horizon Europe work programmes and, in so doing, seek to contribute to the achievement of the United Nations Sustainable Development Goals. Case studies presented here are interdisciplinary by nature and often fall under several Horizon Europe cluster areas, thus illustrating the broad applicability of sex and gender analysis.

The 15 case studies provide concrete examples of how sex and/or gender analysis can lead to new insights, discovery and innovation – and, in a number of cases, how taking into account other social categories intersecting with sex and gender such as ethnicity or age can do so[4].

These case studies cover the health sciences, focusing on how sex and gender analysis contribute to prescription drug development, understanding and treating chronic pain, and improving systems biology. A new, state-of-the-art case study on analysing sex in marine science is presented, demonstrating how understanding sex-based responses to climate change allows better modelling of demographic change among marine organisms and downstream effects on humans. To support a green, sustainable Europe and planet, case studies have been developed in smart mobility and energy solutions, waste management, quality urban spaces and aquaculture. In information and communications technology, three case studies focus on facial recognition, extended virtual reality, and virtual assistants and chatbots. Several new methods are designed to help computer scientists, roboticists, and artificial intelligence researchers and innovators embed gender and intersectional analysis in their technical research. The report

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4   For a background paper, see Tannenbaum, C., Ellis, R. P., Eyssel, F., Zou, J. and Schiebinger, L. (2019), 'Sex and gender analysis improves science and engineering', *Nature*, 575(7781), 137–146 (https://www.nature.com/articles/s41586-019-1657-6.pdf).

also addresses the areas of taxation and economics in case studies on gender-fair taxation and gender equality in venture funding.

Finally, a cutting-edge case study on the impact of sex and gender in the coronavirus disease 2019 (COVID-19) pandemic is included. This case study highlights important findings of gender and sex differences in the effects of COVID-19 on men and women due to biological factors, as well as behavioural differences. Such sex- and gender-sensitive findings build an important foundation for the development of appropriate medical treatments as well as policies to combat the spreading of the virus and its adverse socioeconomic consequences.

The expert group to update and expand Gendered Innovations / Innovations through Gender was led by:

Professor Londa Schiebinger (chairperson)
Stanford University, United States

Professor (emerita) Ineke Klinge (rapporteur)
Maastricht University, Netherlands

The full membership of the group is presented in Chapter 6 of this report.

1. LIST OF CASE STUDIES

Health

▶ Prescription drugs: analysing sex and gender

▶ Systems biology: collecting sex- and gender-specific data

▶ Chronic pain: analysing how sex and gender interact

Climate change, energy and agriculture

▶ Marine science: analysing sex

▶ Smart energy solutions: analysing intersectionality

▶ Agriculture: embedding gender norms in innovation processes

Urban planning, transport

▶ Smart mobility: co-creation and participatory research

▶ Waste management: co-creation and participatory design

▶ High-quality urban spaces: gender impact assessment

Information and communication technology (artificial intelligence, machine learning, robotics)

▶ Extended virtual reality: analysing gender

▶ Facial recognition: analysing gender and intersectionality in machine learning

▶ Virtual assistants and chatbots: analysing gender and intersectionality in social robots

Finance, taxation and economics

▶ Fair tax: gender equality and taxation in the European Union

▶ Venture funding: analysing gender

Ad hoc case study: coronavirus

▶ The impact of sex and gender in the COVID-19 pandemic

2. TERMS

Sex

> **>> SEX** refers to biological characteristics

'Sex' refers to biology. **In humans,** 'sex' refers to the biological attributes that distinguish male, female and intersex. **In non-human animals,** 'sex' refers to biological attributes that distinguish male, female and hermaphrodite. **In engineering and product design research,** sex includes anatomical and physiological characteristics that may affect the design of products, systems and processes.

Defining sex for biomedical research: humans and lab animals

Sex relates to the biological attributes that distinguish male, female and intersex according to functions that derive from the chromosomal complement, reproductive organs, or specific hormones or environmental factors that affect the expression of phenotypic traits in sexually reproducing organisms. These attributes may or may not be aligned in any individual (Fausto-Sterling, 2012; Ainsworth, 2015). Sex may be defined according to the following.

1. **Genetic sex determination:** chromosomal make-up, generally XX/ XY for most mammals. The presence of sex-determining genes means that every nucleated human cell has a sex.

2. **Gametes:** germ cells. In species that produce two morphologically distinct types of gametes, the egg–sperm distinction is the basis for distinguishing between females and males.

3. **Morphology:** physical traits that differentiate female and male phenotypes.

   a. **Primary sex characteristics** in humans and other mammals include the following.

      i. **Internal reproductive organs and genitalia** derive from bipotential organs (e.g. indifferent gonads that become ovaries or testes) and dual structures. Usually, one structure is maintained and the other regressed.

      ii. **External genitalia** generally differentiate towards one of two basic forms: distal vagina, labia and clitoris in females, and scrotum and penis in males. Nevertheless, external genitalia may not reflect karyotypical or internal genital sex (Fausto-Sterling, 2000).

   b. **Secondary sex characteristics** in humans and many other animals are phenotypic traits strongly associated with females or males that become prominent at puberty under the influence of endogenous oestrogens in females and androgens in males. Examples of secondary sex characteristics in humans include shorter stature and wider pelvis, breast development, and more fat in the thighs and buttocks in females, and broader shoulders, greater muscle mass, more facial and other body hair, and male pattern baldness in males. These traits vary within each sex, and ranges overlap. For instance, many women are taller than many men and some women are stronger than many men.

Intersex conditions may be defined as variations or combinations of what are considered XY male-typical and XX female-typical chromosomal, gonadal and genital characteristics. In some cases, intersex individuals (ranging from 1:100 to 1:4 500 depending on the criteria used) have genitalia or other traits not easily categorised as male or female (Kessler, 1998; Karkazis, 2008; Arboleda et al., 2014; Jones, 2018).

Defining sex for research in non-human animals

Sex relates to biological attributes that distinguish male, female and hermaphrodite.

Sex may be defined according to the following.

1. **Genetic sex determination:** chromosomal make-up (female/male), such as XX/XY (mammals), ZW/ZZ (birds and some insects) and XX/XO (insects). Regardless of karyotype, the presence of sex-determining genes means that every nucleated cell has a sex.

2. **Non-genetic sex determination:** common in many species (Gilbert, 2010). These are diverse and include the following.

   a. **Social sex determination.** For a number of fish, mollusc and other species, sex is determined through social interactions with other members of a population. In the slipper limpet *Crepidula fornicata*, all young individuals are male but some later change to female, depending on their position in a mound of snails.

   b. **Environmental sex determination.** In the echiuran worm *Bonellia viridis*, sex is determined by physical environment. Larvae that land on the ocean floor develop as females (~10 cm long), whereas larvae that are engulfed by a mature female through her proboscis develop as males (~2 mm long) and live symbiotically. In all crocodilians, most turtles and some other reptiles, sex determination is determined partially or entirely by temperature. In certain species, sex is genetically determined within a temperature range but environmentally determined outside that range.

3. **Gametes:** germ cells. In species that produce two morphologically distinct types of gametes, the egg–sperm distinction is the basis for distinguishing between females and males. In some species (called sequential hermaphrodites), the type of germ cell produced by an individual can change at different stages of life.

Hermaphrodite describes an individual that is able to produce both male and female gametes during its lifetime. Hermaphroditism is very common in nature, occurring in approximately 30 % of animal species (excluding insects) and most plants (Jarne and Auld, 2006). Hermaphrodites are classified as either simultaneous (individuals functioning as both male and female at the same time) or sequential (individuals first functioning as one sex and then changing to the other at some point). The factors determining the timing, direction and frequency of sex change are diverse throughout nature, and dependent on the species and an individual's social-ecological context (Munday et al., 2006; see case study 'Marine science').

Defining sex for engineering and design

In engineering and product design research, sex includes anatomical and physiological characteristics that may affect the design of products, systems and processes (see Schiebinger et al., 2011–2020). Many devices and machines have been designed to fit male bodies. For example, military and commercial cockpits were traditionally based on male anthropometry, which made it difficult or even dangerous for some women (or small men) to be pilots (Weber, 1997). Crash test dummies are also based on male bodies; while small dummies are now

used to represent women, they do not model bodily differences, such as neck strength (Linder and Svedberg, 2019). Office building thermostats, which are based on male metabolic rates, may set temperatures too low for many women (van Hoof, 2015). Workplace safety gear (e.g. police vests) often does not fit women or small men.

It is also important to understand differences within groups of women, men and gender-diverse people. Many period-tracking apps fail users who have irregular cycles (Tiffany, 2018).

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Gender

>> **GENDER** refers to sociocultural attitudes, behaviours and identities

'Gender' refers to sociocultural norms, identities and relations that (1) structure societies and organisations and (2) shape behaviours, products, technologies, environments, and knowledges (Schiebinger, 1999; Ridgeway and Correll, 2004). Gender attitudes and behaviours are complex and change in time and place. Importantly, gender is multidimensional (Hyde et al., 2018) and intersects with other social categories, such as sex, age, socioeconomic status, sexual orientation and ethnicity (see 'Intersectional approaches' in Annex B). Gender is distinct from sex (Fausto-Sterling, 2012).

Three related dimensions of gender

As social beings, humans function through learned behaviours. How we speak, our mannerisms, the things we use and our behaviours all signal who we are and establish rules for interaction. Gender is one such set of organising principles that structure behaviours, attitudes, physical appearance and habits.

1. **Gender norms** are produced through social institutions (such as families, schools, workplaces, laboratories, universities or boardrooms), social interactions (such as between romantic partners, colleagues or family members) and wider cultural products (such as textbooks, literature, films and video games).

   - Gender norms refer to social and cultural **attitudes** and **expectations** about which behaviours, preferences, products, professions or knowledges are appropriate for women, men and gender-diverse individuals, and may

Gender Norms

Gender Identity

Gender Relations

influence the development of science and technology.

- Gender norms draw upon and reinforce gender stereotypes about women, men and gender-diverse individuals.

- Gender norms may be reinforced by unequal distribution of resources and discrimination in the workplace, families and other institutions.

- Gender norms are constantly in flux. They change by historical era, culture or location, such as the 1950s versus the 2020s, Korea versus Germany or urban versus rural areas. Gender also differs by specific social contexts, such as work versus home.

2. **Gender identities** relate to how individuals or groups perceive and present themselves in relation to gender norms. Gender identities may be context-specific and interact with other identities, such as ethnicity, class or cultural heritage (see 'Intersectional approaches' in Annex B).

3. **Gender relations** relate to how we interact with people and institutions in the world around us, based on our sex and our gender identity. Gender relations encompass how gender shapes social interactions in families, schools, workplaces and public settings, for instance the power relation between a man patient and woman physician.

- Social divisions of labour are another important aspect of gender relations, whereby women and men are concentrated in different types of (paid or unpaid) activities. One consequence of such gender segregation is that particular occupations or disciplines become marked symbolically with the (presumed) gender category of the larger group: for example, nursing is seen as a female profession, engineering as male.

>> **Problems to avoid when analysing gender**

Problems can arise if researchers assume that:

▶ all women as a group, all men as a group and all gender-diverse people as a group (their attitudes, preferences, needs, behaviours and knowledge) are the same;

▶ women, men and gender-diverse people are completely different;

▶ observed differences between women and men are solely biological in origin;

▶ observed gender differences hold across cultures;

▶ life conditions and opportunities are similar for women, men, and gender-diverse people;

▶ birth sex can be used as a proxy for gender identity in surveys;

▶ certain questions are relevant to only one gender (e.g. survey questions about caregiving relate primarily to women or questions about the strain of physical work primarily to men).

- Women and men who work in highly segregated roles acquire different kinds of knowledge or expertise, which can sometimes be usefully accessed for gendered innovations (see 'Co-creation and participatory research' in Annex B; see also Schiebinger et al., 2011–2020a).

- Gender relations can also become embodied in products or urban environments, such as transportation systems (see case study 'Smart mobility').

Sex and gender interact. The term 'gender' was introduced in the late 1960s to reject biological determinism that interprets behavioural differences as the outcomes of biological disposition. 'Gender' was used to distinguish the sociocultural factors that shape behaviours and attitudes from biological factors related to sex. Gendered behaviours and attitudes are **learned**; they are neither fixed nor universal. Nonetheless, gendered experiences can affect biology. Moreover, some individuals seek to change aspects of their bodies to align them better with their gender identities. Sex and gender are often useful analytical terms even if in reality sex and gender interact (see Schiebinger et al., 2011–2020b).

Legal gender categories. Governments typically require citizens to categorise their gender identity on official documents such as birth certificates, driving licences and passports. Numerous countries recognise a third gender category. These include Argentina, Australia, Bangladesh, Canada, Colombia, Denmark, Germany, India, Malta, Nepal, New Zealand and Pakistan, among others.

Cisgender and transgender. 'Transgender' is an umbrella term that describes a range of gender identities, including individuals whose gender identity differs from that typically associated with the sex they were assigned at birth (Marshall et al., 2019; Scandurra et al., 2019). This is in contrast to 'cisgender', which describes individuals whose self-identified gender matches their birth sex assignment (Aultman, 2014). Other individuals refuse the concept of gender as binary altogether and may self-identify as genderqueer, non-binary, gender-fluid or bigender (Hyde et al., 2018).

Gender is multidimensional. Gender is often described as existing on a masculinity–femininity spectrum, but such categories can reinforce stereotypes about women and men, and ignore individuals who fall outside traditional gender binaries (Nielsen et al., forthcoming). Gender is multidimensional: any given individual may experience configurations of gender norms, traits and relations that cannot be subsumed under the simple categories 'feminine' and 'masculine'.

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Intersectionality

'Intersectionality' describes overlapping or intersecting categories such as gender, sex, ethnicity, age, socioeconomic status, sexual orientation and geographical location that combine to inform individuals' identities and experiences.

Researchers and engineers should not consider gender in isolation; gender identities, norms and relations both shape and are shaped by other social attributes (Buolamwini and Gebru, 2018).

In 1989, the legal scholar Kimberlé Crenshaw coined the term 'intersectionality' to describe how multiple forms of discrimination, power and privilege intersect in Black women's lives, in ways that are erased when sexism and racism are treated separately (Crenshaw, 1989). Since then, the term has been expanded to describe intersecting forms of oppression and inequality emerging from structural advantages and disadvantages that shape a person's or a group's experience and social opportunities (Hankivsky, 2014; Collins and Bilge, 2016; McKinzie and Richards, 2019; Rice et al., 2019).

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3. LIST OF METHODS

Sex and gender can influence all stages of research and innovation, from strategic considerations for establishing priorities and building theory to more routine tasks of formulating questions, designing methods and interpreting data. Many pitfalls can be avoided – and new ideas or opportunities identified – by designing sex and gender analysis into research and innovation from the start.

Sex and gender analyses work together with other methodologies in a field, and with intersectional approaches that take into account intersections with other social factors, such as ethnicity, gender identity and sexual orientation, in order to provide filters for bias and contribute to excellence in science and technology.

As with any set of methods, new ones will be fashioned and others discarded as circumstances change. The value of their implementation depends on the creativity of the research and/or innovation team. There is no recipe that can simply be plugged into research or development processes. Researchers and innovators will want to consider all methods and think creatively about how these methods can enhance their research and innovations.

The methods listed below have been developed by the Horizon 2020 (H2020) Expert Group to update and expand Gendered Innovations / Innovation through Gender (Gendered Innovations 2).

These methods, described in Annex B, are applied in the case studies detailed in Annex A. Case study abstracts are presented in the next chapter.

General methods

▶ Analysing sex

▶ Analysing gender

▶ Intersectional approaches

▶ Co-creation and participatory research

▶ Asking about gender and sex in surveys

Field-specific methods

▶ Health and biomedicine

- Analysing gender in health and biomedicine

- Analysing sex in tissues and cells

- Analysing sex in lab animal research

- Analysing sex in biomedicine

▶ Information and communication technologies

- Analysing gender and intersectionality in machine learning

- Analysing gender and intersectionality in social robotics

▶ Climate change

- Analysing sex in hermaphroditic species

▶ Urban planning/transportation

- Gender impact assessment

▶ Innovation

- Norm-critical innovation

In addition to these newly developed or up-dated methods, methods developed previously by the Gendered Innovations 1 Expert Group (Schiebinger et al., 2011–2020) include:

rethinking research priorities and outcomes

rethinking concepts and theories

formulating research questions

analysing how sex and gender interact

engineering innovation processes

design thinking

rethinking standards and reference models

rethinking language and visual representations.

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Schiebinger, L., Klinge, I., Sánchez de Madariaga, I., Paik, H. Y., Schraudner, M. and Stefanick, M. (eds.) (2011–2020), 'Methods of sex and gender analysis', Gendered Innovations in Science, Health & Medicine, Engineering, and Environment (http://genderedinnovations.stanford.edu/methods-sex-and-gender-analysis.html).

4. ABSTRACTS OF THE 15 CASE STUDIES

Health

PRESCRIPTION DRUGS: ANALYSING SEX AND GENDER

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The challenge

Historically, drug development has followed a 'one size fits all' model. Drug testing has been conducted predominantly on males, from pre-clinical research in rodents to clinical trials. As a result, women report more unwanted, and sometime deadly, side effects than men.

Method: analysing sex

Females and males must be included in all drug trials – from early cell and animal testing to human clinical trials – and analysed separately. Age and genetic ancestry should also be considered, as these characteristics may affect drug efficacy, safety and toxicity. Pregnancy also requires attention, as pregnant women become ill and ill women become pregnant. Information about drug safety effects on the foetus is a priority.

Method: analysing gender

Gender stereotypes can affect clinical care in several ways. First, gender and age bias can influence diagnostic questions. Physicians and researchers should pay attention to language and gender norms in diagnostic procedures. Second, gender relations between the healthcare provider and the patient can affect prescribing patterns and treatment outcomes. Age and race can also play a role.

Gendered innovations

1. **Including females and males in all stages of drug development** will help us understand sex differences in efficacy, toxicity and safety. This will allow the development of sex-specific dosing, when necessary, or treatments.

2. **Disaggregating reporting of side effects by sex** represents an essential step to increase our understanding of how medications work differently in women and men in real-world settings.

3. **Reporting sex differences on drug labels** helps prescribers and patients administer the right drug in the right dose to the right person at the right time.

4. **Promoting gender-transformative treatment approaches** eliminates gender bias and stereotypes in diagnostic questions, allowing better detection of symptoms in women, men and gender-diverse people.

SYSTEMS BIOLOGY: COLLECTING SEX- AND GENDER-SPECIFIC DATA

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The challenge

Sex and gender roles can affect the human metabolism. Consequently, prevention and treatment of many non-communicable diseases require a sex- and gender-related approach. Systems biology aims to predict individual disease risk and enable precision treatment by mathematically modelling metabolic processes. Such models are based largely on omics data (i.e. genomics, transcriptomics, proteomics, metabolomics). Sex bias in the collection of these datasets, however, leads to sex bias in the mathematical models and their predictions.

Method: collecting sex- and gender-specific data

The amount, quality and precision of data have an essential influence on research output. The growing use of large datasets and their integration in fields such as precision medicine, pharmacotherapy and nutrition bring this aspect to the forefront. When collecting information about sex, clear decisions need to be made on how sex is operationalised (e.g. through genomic data alone or in combination with hormonal profiles and phenotypes). The same applies to the potential inclusion of gender in these analyses. Currently, the only immediately available option is the collection of data about gender identity; however, as instruments become more refined, information on gender norms and behaviours could also be collected. The integration of this information could generate new personalised therapies or preventative offers.

Gendered innovations

1. **Collecting data on sexual dimorphism in gene expression** improves biological modelling. Accurate biological modelling requires more studies of sexual dimorphism in human gene expression. Such studies should also take into account different ethnic, cultural and societal backgrounds, and different lifestyles.

2. **Collecting sex and gender data** fuels integrative omics. Integrative omics provides a basis for sex-specific precision applications in various fields such as medicine, pharmacotherapy and nutrition. Current datasets underrepresent females and underreport participants' gender identity.

3. **Analysing sex** improves understanding of the role of the microbiome in health and disease. Sex differences are found in the gut microbiome. Analysing these differences will enhance our understanding of how the microbiome influences the human metabolism and sharpen our efforts to improve human health.

4. **Integrating sex difference** improves systems biology models. Some researchers are retrofitting male models to account for sex differences. Researchers and funding agencies have a role to play in correcting sex bias in omics experiments.

CHRONIC PAIN: ANALYSING HOW SEX AND GENDER INTERACT

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The challenge

Sex and gender affect all parts of the pain pathway, from signalling through perception and expression to treatment. Recent studies have shown that women generally display a lower pain threshold for all types of pain: pressure, heat, cold, chemical or electrical stimulation and ischaemia. Some researchers attribute these differences solely to biological (sex) differences; others suggest that these observed differences are, at least in part, due to gender. The fact that women and men are raised to express pain differently may modify both their biological response to pain and their willingness to report it. A better understanding of biological (sex) and sociocultural (gender) mechanisms of pain, and how these interact with pain management regimes, may lead to better health outcomes for pain patients.

Method: analysing how sex and gender interact

Biological mechanisms, such as sex hormones, influence the nervous and immune systems and thus the signalling, perception and expression of pain, and response to treatment of it. Gender roles and norms also influence pain. Gender norms, which vary between cultures, affect a patient's perceived sensitivity to pain. During childhood, boys may be taught to be tough and stoic, and girls to verbalise discomfort. Researchers have demonstrated that these gender norms can be changed and that this can affect perceived sensitivity to pain. Thus, observed biological differences (sexual dimorphism) might also be a consequence of gendered social and environmental influences.

Gendered innovations

1. **Studying the underlying biological mechanisms of pain in female-typical bodies and male-typical bodies.**
   A better understanding of the influence of biological sex on the nervous and immune systems might help researchers design sex-specific pain treatments.

2. **Studying how sex and gender interact, and how sex and sex interact.** Men/boys, women/girls and gender-diverse individuals are socialised to respond differently to pain and this might influence their sensitivity to pain. Researchers' sex might also influence a research subject's sex-related response to pain.

3. **Understanding how gender affects the reporting and treatment of pain.**
   Gender stereotypes can influence how pain is experienced, a patient's willingness to report pain and how healthcare professionals manage pain.

Climate change, energy and agriculture

MARINE SCIENCE: ANALYSING SEX

Image by Moica J from Pixabay

The challenge

Sex analysis is largely overlooked in marine science. A recent systematic review of ocean acidification literature, for example, revealed that only 3.7 % of recent studies tested for sex differences, and 85 % of studies failed to consider sex at all. Failing to account for such differences affects our ability to manage ecosystems effectively and set conservation priorities.

Method: rethinking concepts and theories

The inclusion of sex in marine science requires challenging the widely held perception that sex plays no role in determining biological responses to environmental disturbances. We must also move beyond the assumption that sex is binary, fixed and genetically determined. Nature abounds with examples of sex along a continuum, labile sex and sex determined by an interacting suite of genetic, hormonal, physiological, social and/or environmental processes. In order to understand the importance of sex for basic biology, it is important to consider the mechanisms, timings and direction of sex determination and differentiation, as well as differences in female, male and hermaphroditic responses to environmental perturbation.

Method: analysing sex

Studies that disaggregate and analyse data by sex have highlighted the importance of considering female and male responses to climate change. In many marine organisms, sex cannot be easily seen. What is needed now is novel, non-invasive methods of sex analysis in non-model organisms, an effort that will be facilitated by the increasing affordability of omics approaches.

Gendered innovations

1. **Understanding feminisation of marine organisms in a warming ocean** is critical to elucidate the threat that climate change poses to animals whose sex is determined by temperature, such as marine turtles. Understanding such phenomena is vital to assess extinction risk under future climate change scenarios.

2. **Understanding environmental sex determination beyond temperature** is vital to population demography in a number of organisms of economic, ecological and experimental importance to humans under future climate change scenarios.

3. **Effective population management using sex analysis** will enable continued sustainable exploitation of natural resources.

4. **Understanding the differential sensitivity of female and male marine organisms to climate change** is critical to fully document the impact of environmental change on populations and ecosystems.

SMART ENERGY SOLUTIONS: ANALYSING INTERSECTIONALITY

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The challenge

In the EU, buildings are responsible for approximately 40 % of energy consumption and 36 % of CO_2 emissions. They are therefore the single largest energy consumer in Europe. For climate change solutions, the world needs an effective energy transition. This energy transition depends, at least in part, on users' acceptance of new technologies and services, and on robust public engagement in conceptualising, planning and implementing low-carbon energy solutions. This case study analyses how to integrate gender and intersectional analysis into energy research and into the development, design and commercialisation of energy products and services in order to maximise the adoption of new energy efficiency tools and technologies.

Method: engineering innovation processes

Energy efficiency tools and solutions need to attract everyone, both men and women, in order to support an effective energy transition. Although many energy-efficient technologies and products are available, they are often rejected by users in households, the public sector and industry because they do not meet the values, motivations and needs of different user groups, which are shaped and influenced by gender norms and different lifestyles. Redesigning the engineering process can lead to broader acceptance of energy efficiency tools and products.

Method: analysing intersectionality

The energy debates often ignore the human factor. An intersectional approach is needed, one that recognises people's multiple, interdependent and overlapping axes of social identity, e.g. gender, socioeconomic status and age. A single factor, such as gender, both shapes and is shaped by other social attributes such as age, ethnicity and socioeconomic status. Together, these factors influence the life experiences of citizens engaging with the complex sociotechnical networks that constitute the energy system.

Gendered innovations

1. **Designing energy-efficient tools that integrate gender perspectives.** Redesigning the engineering innovation process has led to new opportunities for environmental and economic solutions that can propel the energy transition by increasing users' adoption of novel technologies.

2. **Driving the energy transition by taking an intersectional approach to gender, age and socioeconomic factors.** Energy researchers, companies, policymakers and researchers need to better understand the role that gender and other social, economic and demographic factors play in energy policy. Gender analysis and intersectional analysis are required for effective and equitable energy technologies and policies.

AGRICULTURE: EMBEDDING GENDER NORMS IN INNOVATION PROCESSES

Image from www.pikist.com

The challenge

Agricultural innovations tend to affect women and men differently. Most innovations focus on resolving technical problems, such as raising yields, withstanding environmental stress and managing poor soil or seeds. Such innovations often fail to account for (1) how gender norms influence the implementation of technical solutions or (2) how the implementation of technical solutions will influence gender norms. Consequently, innovations may not reach women and may even amplify gender inequality.

Method: analysing gender

Gender experts across the Consultative Group on International Agricultural Research (CGIAR) created Enabling gender equality in agricultural and environmental innovation (Gennovate), aimed at developing gender-transformative approaches that embed gender norms in innovation processes.

These include:

1. fostering critical examination of gender roles, norms and relations;

2. recognising and strengthening positive norms that support equality;

3. promoting the position of women, girls and marginalised groups;

4. transforming underlying social structures, policies and widely held beliefs that perpetuate gender inequality.

Gendered innovations

1. **Gill nets in Bangladesh.** Gender-related cultural and religious expectations prohibit women in rural Bangladesh from harvesting fish, even from their own ponds. Such tasks are seen as the responsibility of men. Women are also reluctant to enter ponds because they get their saris wet. To support gender equality and to ensure food security, WorldFish, a part of the CGIAR, introduced gill nets in the poorest parts of Bangladesh. The nets, which women can make themselves, are used to catch the nutrient-rich mola fish. Crucial to the success of this project were initiatives addressing gender consciousness to ensure that husbands, in-laws and neighbours supported the new role of women in cultivating fish and catching them with gill nets.

2. **Embedding gender norms in innovation processes.** CGIAR gender experts have proposed in-depth research methods to include gender norms in large-scale agricultural research and development (R & D) programmes. In a 4-year project (2014–2018) sponsored by the Bill and Melinda Gates Foundation, they collaborated in Gennovate to develop extensive methodologies, reports, articles, briefs and videos as resources for research teams, and to understand how gender norms and innovation processes in the management of agriculture and natural resources influence each other in diverse rural settings.

Urban planning, transport

SMART MOBILITY: CO-CREATION AND PARTICIPATORY RESEARCH

Image from www.maxpixel.net

The challenge

Mobility patterns tend to be gendered in terms of where, when and why people take trips from home. Transportation planning – for both modes and infrastructures – often does not take into account the diversity of needs and issues that affect transportation. For example, the need for safety can restrict mobility opportunities for specific groups.

Method: co-creation and participatory research

National Household Travel Surveys form an important database for mobility analysis and transport planning. However, they underrate trips performed as part of caring work, i.e. doing errands to meet household needs or to accompany or care for others in the household. Surveys that include such aspects explicitly help to illuminate mobility needs. To go beyond observation and analysis of mobility evidence, participatory research and co-creation help planners integrate users' gender-specific needs into the process of new service and technology development from the outset.

Gendered innovations

1. **Understanding gender-specific needs for mobility services.** An understanding of gender-specific needs throughout populations can add new perspectives to the collection of mobility data and can improve transportation for broader segments of the population. Attention should also be paid to other factors, such as age, abilities, ethnicity and socioeconomic status.

2. **Creating new services and developing new technology design for mobility.** Developing and applying gender-sensitive methodologies to assess gender-specific needs can improve mobility options for more passengers, and simultaneously promote environmentally friendly mobility behaviours.

WASTE MANAGEMENT: CO-CREATION AND PARTICIPATORY DESIGN

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The challenge

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change on urban and land use planning calls for adaptation and mitigation strategies to combat climate risk in cities. Innovative approaches to urban waste management will help reduce CO_2 emissions and increase the sustainability of cities and regions. This case study highlights Horizon 2020 research on mainstreaming gender analysis into urban strategies for waste prevention and management.

Method: co-creation and participatory design

Participatory approaches are based on co-creation and co-design to investigate the needs of different user groups when designing new methods, tools and instruments from a gendered perspective. Both approaches are based on gendered participatory research using information and communication technology (ICT).

Gendered innovations

1. **Collecting data on gendered waste behaviours and intervening to change user behaviours.** It is important to understand and minimise waste production in order to reduce greenhouse gas emissions. This will help cities and regions reach the EU's 2050 climate goals.

2. **Using participatory gender mainstreaming** to collect sex-disaggregated data on waste behaviours and to foster women's participation in waste management. Mainstreaming gender analysis into waste management innovates and transforms how we think about waste.

HIGH-QUALITY URBAN SPACES: GENDER IMPACT ASSESSMENT

The challenge

The quality of urban spaces in everyday life is important for many, particularly children, caregivers and elderly people. These groups spend more time in public spaces than working-age women and men, and may face specific risks in public spaces. They are more likely to suffer life-limiting conditions when public spaces do not provide basic amenities supporting their daily needs or are not safe. Planning and designing public spaces that respond to the specific everyday needs of mothers of young children, children and the elderly is required to make cities work for all. This case study will look at innovations and methods used in various cities to improve the quality of urban spaces for working mothers, children and the elderly, in both suburban and dense urban environments, in the developed and the developing countries.

Method: gender impact assessments

Gender impact assessments allow city planners to understand who benefits from urban design and who is left out. From the results, conclusions can be drawn about what could be relevant for broader applications. Gender impact assessments produce systematic evaluations for developing more general recommendations. Where relevant, these assessments should include intersectional variables, such as age, ethnicity, physical ability and geographical location.

Gendered innovations

1. **Building child-friendly and family-friendly streets and public spaces.** Streets and urban public spaces are often designed and built giving priority to the needs of cars over the needs of people. High-quality streets and public spaces require careful attention to the daily needs of people, particularly of children, the elderly and their caregivers.

2. **Building playgrounds for children of different ages and genders.** Children of different ages and genders use spaces in different ways, which sometimes conflict with one another. Considering the specificities of age and gender will improve the quality of playgrounds for all children.

Information and communication technology (artificial intelligence, machine learning, robotics)

EXTENDED VIRTUAL REALITY: ANALYSING GENDER

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The challenge

Research measuring progress in achieving gender equality concludes that innovative solutions are still required. Technologies such as extended virtual reality have been found to be useful for promoting gender equality by reducing bias and increasing empathy.

Method: analysing gender

'Extended virtual reality' refers to technologies such as virtual reality (VR), augmented reality (AR) and mixed reality (MR), which incorporate elements of the virtual world into our real world, thus enhancing the things we see, hear and feel. These technologies may prove fruitful in promoting gender equality; however, they also come with risks. Research shows that women, men and gender-diverse people may differ in how they experience virtual environments. These potential gender differences need to be taken into account in the development and testing of prototypes.

Gendered innovations

1. **Developing empathy through extended reality (XR).** VR and AR may help us develop higher levels of empathy in specific contexts, which can, in turn, reduce implicit bias.

2. **Promoting gender equality through VR.** VR provides a technology for humans to create imaginary worlds – in this case, virtual worlds where gender equality exists – with the hope that these experiences will modify behaviours in the real world.

3. **Improving healthcare with XR.** XR technologies are increasingly used for diagnosing and managing patients. These technologies may improve women's health, for example by aiding early diagnosis of breast cancer or managing the symptoms of menopause. Studies have also shown that virtual reality is an effective tool to engage men in preventative healthcare; for example, men tend to seek screening for testicular disorders after being exposed to virtual reality interventions.

FACIAL RECOGNITION: ANALYSING GENDER AND INTERSECTIONALITY IN MACHINE LEARNING

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The challenge

Facial recognition systems (FRSs) can identify people in crowds, analyse emotion, and detect gender, age, race, sexual orientation, facial characteristics, etc. These systems are often employed in recruitment, authorising payments, security, surveillance or unlocking phones. Despite efforts by academic and industrial researchers to improve reliability and robustness, recent studies demonstrate that these systems can discriminate based on characteristics such as race and gender, and their intersections. In response, national governments, companies and academic researchers are debating the ethics and legality of facial recognition. One point is to enhance the accuracy and fairness of the technology itself; another is to evaluate its use and regulate deployment through carefully implemented policies.

Method: analysing gender and intersectionality in machine learning

Bias in machine learning (ML) is multifaceted and can result from data collection, or from data preparation and model selection. For example, a dataset populated with men and lighter-skinned individuals will misidentify darker-skinned females more often. This is an example of intersectional bias, in which different types of discrimination amplify negative effects on an individual or group.

Gendered innovations

1. **Understanding discrimination in facial recognition.** Each step in an FRS – from face detection to facial attribute classification, face verification and facial identification – should be checked for bias. To work, models must be trained on datasets that represent the target population. Models trained on mature adults, for example, will not perform well on young people.

2. **Creating intersectional training datasets.** To work properly in tasks such as validating the identity of people crossing international borders, training datasets may need to include intersectional characteristics, such as gender and race. The Gender Shades project, based at the Massachusetts Institute of Technology (MIT), developed and validated such a dataset for four categories: darker-skinned women, darker-skinned men, lighter-skinned women and lighter-skinned men.

3. **Establishing parameters for a diverse set of faces.** Wearing facial cosmetics can reduce the accuracy of facial recognition systems by 76 %. Transgender people, especially during transition, may be identified incorrectly. Publicly available face databases need to establish parameters to improve accuracy across diverse categories without endangering those communities.

VIRTUAL ASSISTANTS AND CHATBOTS: ANALYSING GENDER AND INTERSECTIONALITY IN SOCIAL ROBOTS

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The challenge

Chatbots and virtual assistants are often biased. Personal assistants, for example, are often feminised, reproducing harmful gender stereotypes about the role of women in society and the type of work women perform. The datasets and algorithms used in these artificial intelligences (AIs) may also be biased, perpetuating existing discrimination and incorrectly interpreting the language of certain ethnic or socioeconomic groups.

Method: analysing gender and intersectionality in social robots

When designing virtual assistants and chatbots, it is important to consider how they might perpetuate stereotypes and social inequalities. The designers of virtual assistants should be aware of how robots are gendered, e.g. by name or voice. Designers should adopt a participatory research approach to better understand how conversational AI agents can better fit a diverse group of users, based on intersecting traits such as gender, ethnicity, age and religion.

Gendered innovations

1. **Combating the harassment of conversational AI.** Feminised chatbots are often harassed. Pushing back on harassment presents an opportunity for AI to help stop gender and sexual harassment.

2. **De-biasing data and algorithms.** Virtual assistants need to be trained on a wide variety of language so that they do not discriminate against gender- and ethnic-specific language variations or slang.

3. **Gender-neutral conversation.** To combat the harm caused by feminised virtual assistants, companies and researchers are developing gender-neutral voices and gender-neutral language that does not exclude women or gender-diverse people.

Finance, taxation and economics

FAIR TAX: GENDER EQUALITY AND TAXATION IN THE EUROPEAN UNION

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FairTax

The challenge

Tax laws can be structurally discriminatory because of socioeconomic inequalities, such as those that exist between men and women. A thorough understanding of gender aspects in tax policies, the implementation of legal and political requirements, and the realisation of gender equality requires many reforms and future research.

Method: analysing gender

This case study is based on critical cross-disciplinary gender analyses. On the economy, it employs literature reviews, macroeconomic modelling, statistical comparisons and microsimulations. On the law, it employs doctrinal law studies, of both hard law (legal obligations that are binding and can be enforced before a court) and soft law (agreements, principles and declarations that are not legally binding). On tax policies, it employs soft law regulations and policies, combined with historical and comparative framework analyses.

Gendered innovations

1. **Understanding the impact income tax systems have on secondary earners.**
National tax systems of EU Member States have fuelled inactivity traps for secondary earners, hindering the equal participation of women in the labour market. To overcome this problem, the European Parliament has recommended that Member States phase in full individual taxation in their income tax systems, including the elimination of tax expenditures and benefits based on joint income.

2. **Developing a new concept for fair and sustainable taxation that merges gender equality and tax policies.**
Gender-differentiated outcomes of tax policies result in the neglect of tax objectives, such as fairness linked to redistributive aspects of taxation. To alleviate this problem and reduce income inequalities, the European Parliament has called on Member States to retain progressive income tax systems and to pay attention to the role of taxes on corporations, wealth and capital.

VENTURE FUNDING: ANALYSING GENDER

Image by Mabel Amber from Pixabay

The challenge

Entrepreneurship is one possible way to help women to empowerment and economic citizenship, and at the same time ensure necessary products and services for all, and thereby contribute to welfare development. However, women globally earn less than men, have fewer savings and own less property, i.e. women have less financial capital to put into venture creation to start their own businesses. In addition, the venture capital (VC) industry is highly gender-skewed. In the EU, firms with a woman chief executive officer (CEO) receive only 11 % of VC funding. In the United States, the percentage is even lower. Only 3 % of women-led firms receive VC funding, and that number has not changed over the last two decades. Further, statistics from the VC industry itself show that women hold few positions in the VC industry: 3 % of managing directors are women, 4 % of vice presidents are women and 2 % of investment managers are women. The relationship between the capital demand side (entrepreneurs) and the capital supply side (investors) should be a major concern for politicians and policymakers who want to understand – and change – how gender affects new venture funding, and thereby contribute to there being more women entrepreneurs.

Method: analysing gender

Gendering the theory used to generate knowledge about the VC industry is one step towards overcoming the gender gap in venture funding. This creates awareness that knowledge production, i.e. research results, is often gendered. In this case we investigate how gender functions in signalling theory. Signalling theory is one example of theories used when learning more about venture funding. Gender cannot be treated as a separate variable; it must be understood as embedded in the relations in which entrepreneurs operate.

Gendered innovations

1. **Including gender analysis in theory on venture funding.** Signalling theory that analyses the entrepreneur–investor relationship, for example, can consider how gender functions with respect to the signaller, the receiver, the signal and the feedback.

2. **Identifying the impact of venture funding systems on women's entrepreneurship.** Entrepreneurship and capital ownership are dominated by men, and women entrepreneurs must clearly communicate their legitimacy in order to overcome the inherent gender bias in the interpretation of signals.

Ad hoc case study: coronavirus

THE IMPACT OF SEX AND GENDER IN THE COVID-19 PANDEMIC

The challenge

Although infectious diseases can affect everyone, sex and gender can have an impact on immune responses and the course of the disease in the human body. Biological impacts of the pandemic intersect with broader social and systemic challenges, such as limited healthcare and economic and logistical resources. Current worldwide statistics on COVID-19 show more men than women dying of acute infection, while women are projected to suffer more than men from the health, economic and social consequences of the pandemic in the long term. Innovative solutions beyond health, such as economic re-entry strategies, product development and AI solutions, also need to consider sex and gender.

Method: analysing sex

All data related to COVID-19 morbidity and mortality should be disaggregated by sex. Females generally respond more intensely to contact with viruses, such as severe acute respiratory syndrome coronavirus 2 (SARS-CoV2), both through natural infection and through vaccination. Potential impacts of these differences should be considered in diagnostics and therapeutics. Studies of COVID-19 need to integrate the sex variable, by using female and male cells and experimental animals in drug discovery and preclinical research, and women and men in clinical trials. All drug and vaccine trials should include sex-specific analyses, as females develop side effects more frequently than males.

Method: analysing gender

Preventative measures should be designed in a gender-sensitive manner. Women reportedly comply more with hand hygiene. Gender affects the division of labour and care duties in families. Women are more often employed in professions with a high risk of infection, such as healthcare, and are more often responsible for the care of sick family members. The allocation of protective equipment, therapies and financial aid should be gender-equitable. Gender-sensitive design should be used when developing digital resources for preventative measures.

Gendered innovations

1. **Studying sex differences in the immune response** could help address the higher COVID-19 mortality in men than in women.

2. **Focusing on dosing and sex-specific side effects of vaccines and therapeutics** will be essential in the development of therapeutic responses against SARS-CoV2 infection and COVID-19.

3. **Analysing gender-specific risk factors** may help decrease mortality in women in the long term. In the EU, 76 % of healthcare workers are women. This has the potential to expose them significantly more to the virus; hence the need for fitted personal protective equipment.

4. **Designing gender-sensitive prevention campaigns** can increase compliance and reduce exposure. For effective public health campaigns, gender-specific preferences should be analysed and deployed in preventative measures, digital platforms, data collection wearables and AI prediction models.

5. **Considering the gender-specific socioeconomic burden of public safety measures** can mitigate their inequitable impact. Public health emergencies can lead to the disruption of gender roles. Women and gender-diverse individuals are at significantly more risk of experiencing economic insecurity, discrimination and gender-based violence.

5. POLICY RECOMMENDATIONS FOR HORIZON EUROPE

1. European Union policy context

Integrating sex and/or gender analysis into the contents of R & I adds value to research in terms of excellence, creativity and business opportunities. Considering sex and/or gender analysis along with intersecting categories, such as ethnicity and socioeconomic status, also fosters innovation and enhances equality by ensuring that findings, products and programmes apply to all citizens and society as a whole.

Policy is one driver of excellence in R & I. These policy recommendations aim to increase both the scientific quality and the societal relevance of R & I projects funded under Horizon Europe. These recommendations also support the political priorities set forth by the European Commission President, Ursula von der Leyen, and strengthen the EU's response to global challenges, such as the achievement of the UN Sustainable Development Goals (SDGs), and pandemics, such as the COVID-19 outbreak.

The European Commission is a global leader in policy for integrating the gender dimension into R & I content, which was set as a priority for Horizon 2020. The proportion of 'gender-flagged' topics – i.e. topics that explicitly require sex and/or gender analysis in funded projects – has increased in every successive work programme, expanding from 16.1 % of topics in 2014–2015 to 36.4 % in the 2020 work programme[5]. Execution of this policy, however, has been lagging. The interim evaluation of gender as a cross-cutting issue revealed that fewer than expected research proposals funded under gender-flagged topics successfully incorporated sex and gender analysis. Evaluators traced this poor uptake to

an 'absence of training on gender issues' (European Commission, 2017, p. 26).

Based on the work of this expert group, these policy recommendations acknowledge and build on:

▶ the strengthened commitment to gender equality put forth in Horizon Europe and embedded in the orientation document developed for the first Horizon Europe strategic plan (European Commission, 2019a);

▶ the new gender equality strategy 2020–2025 (European Commission, 2020a) adopted by the European Commission on 5 March 2020, which proposes that Horizon Europe fund gender and intersectional research to help debunk gender stereotypes and foster equality in all domains.

The following set of concrete recommendations have been elaborated by the H2020 Expert Group to update and expand Gendered Innovations / Innovation through Gender to foster the effective integration of the gender dimension into R & I content throughout the next framework programme.

These recommendations assume an overall ambitious policy approach to foster and support gender equality in all aspects of R & I in the European Union. Such an approach addresses other gender equality objectives through general rules and targeted measures to ensure:

▶ increased participation of women in the programme, and gender balance in funded project teams;

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[5] Provisional data for calls launched before July 2020 (including topics under the two special coronavirus calls for expression of interest), to be updated with remaining call topics (e.g. European Green Deal).

gender balance in decision-making structures;

▶ the realisation of institutional change in R & I organisations through gender equality plans, which includes integrating the gender dimension into R & I and teaching content in higher education institutions, and entails providing comprehensive policy support to Member States, research-performing and research-funding organisations, businesses and innovation companies.

These objectives should be embedded in Horizon Europe and also integrated into the framework of the future European Research Area (ERA) by mobilising Member States and Associated Countries to foster gender equality in R & I actions at the national level.

2. Work programmes

Integrating the gender dimension into Horizon Europe work programmes as the norm

In line with the proposal for a decision of the Council establishing the specific programme implementing Horizon Europe (Council of the European Union, 2019), integrating the gender dimension into R & I content should be considered as a matter of principle throughout the programme.

▶ We therefore recommend that all Horizon Europe topics, by default, require sex- and gender-based analysis, unless topic drafters clearly demonstrate that the gender dimension is not relevant to the proposed topic.

▶ This entails installing a 'negative' gender-flagging, by which only topics not requiring the gender dimension would be flagged, thus reversing the burden of proof.

▶ To execute this approach, topic descriptions should explicitly require proposals to include details about how

sex and/or gender analysis will be integrated into the R & I content and specify how the work will contribute to achieving the topic's target outcomes. A topic's target outcomes should include combating and transforming gender norms and stereotypes, fostering broad social equalities and advancing SDG 5, gender equality.

▶ At the level of the call (which covers a set of topics, under a particular intervention area), the relevance of sex and/or gender analysis should be specified and related to the call's targeted impacts. Examples of gender-related targeted impacts, for each Horizon Europe Pillar II cluster and mission, are provided in Section 5.6 of this document and based on the case studies developed by this expert group.

▶ For bottom-up work programme parts, such as the European Research Council's calls and the Marie Skłodowska-Curie actions calls under Pillar I of Horizon Europe as well as European Innovation Council calls under Pillar III, the work programmes should explicitly encourage applicants to integrate the gender dimension into their proposals, wherever relevant.

Dedicated call topics for advancing gender knowledge

▶ In addition to this gender mainstreaming approach throughout the programme, Horizon Europe should include call topics specifically dedicated to developing knowledge of gender equality issues.

▶ In an improvement on Horizon 2020, the Horizon Europe Specific Programme (Council of the European Union, 2019) and the *Orientations towards the first strategic plan for Horizon Europe* (European Commission, 2019a) now include, under Cluster 2, 'Culture, creativity and inclusive

society', of Pillar II, 'Global challenges and European industrial competitiveness', a broad line of activity supporting the development of cross-disciplinary gender research, i.e. advanced strategies and innovative methods for promoting gender equality in all social, economic and cultural domains.

▸ We welcome this important novelty and recommend among topics to be considered:

- the development of gender knowledge related to all SDGs;

- the development of intersectional knowledge, investigating in particular the multidimensional interactions between gender norms, gender relations, gender identity and sexual orientation (LGBTI+ issues[6]), ethnicity, socioeconomic status, age, language, geographical location, religion, etc.

▸ Moreover, the Horizon Europe work programme part entitled 'Reforming and enhancing the European R & I system' of 'Widening participation and strengthening the European Research Area', which furthers the gender equality objectives that were addressed under the Science with and for Society work programme of Horizon 2020, should also be a vector for supporting the integration of the gender dimension into R & I content and higher education curricula at a structural level in R & I organisations. In particular, funding should be made available to support policy work with national research-funding organisations to foster policies and programmes aimed at ensuring that R & I integrates sex, gender and/or intersectional approaches.

3. Instructions for Horizon Europe applicants, evaluators and reviewers

Practical guidance and briefing materials need to be developed to assist applicants, evaluators and reviewers to better understand the gender dimension. This includes inserting points relevant to integrating the gender dimension into R & I content into instructions to applicants, evaluators and reviewers, and updating those points. They should be tailored to different fields of R & I and, more specifically, to the different Pillar II clusters.

Briefing materials

The expert group recommends the development of:

1. *Infosheets* for applicants, evaluators, reviewers and topic drafters, drawn from the gendered innovations case studies, methods, terms and infographics concept developed by the expert group, to be included in all briefing and training materials.

2. *Factsheets* for the general public consisting of major R & I findings presented briefly and visually.

Training

The gender dimension in R & I content is a field of specialised expertise. Staff in the Directorate-General for Research and Innovation (DG R & I), applicants and evaluators need sophisticated understandings of how to integrate sex and gender analysis into R & I content. Training should be offered systematically throughout the Horizon Europe ecosystem.

▸ Tailored training on integrating sex, gender and intersectional analysis into R & I content should be developed for key players involved in developing and

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[6] LGBTI+ stands for lesbian, gay, bisexual, transgender, intersex and other diverse sexual orientations and gender identities.

implementing Horizon Europe work programmes, including topic drafters/scribes, programme officers and call coordinators, moderators and rapporteurs, proposal evaluators and project reviewers, mission board members and national contact points.

▶ The DG R & I should provide in-person or online training for Horizon Europe applicants, evaluators and reviewers. Researchers do not necessarily know what the 'gender dimension' means or how to integrate it into R & I using state-of-the-art methods (see Annex B of this document). We recommend that these courses be mandatory for all Horizon Europe proposal evaluators and available to applicants.

▶ In dialogue with relevant stakeholders (see Section 5 below), the DG R & I should promote and offer training for staff in European research-performing and research-funding organisations.

Proposal templates

Proposal templates are important, and here we offer specific guidelines.

▶ All Horizon Europe topics are considered by default to require sex- and gender-based analysis, unless a topic is negatively flagged.

- This requirement should be clearly signalled to all applicants.

  - Under the 'excellence' criterion, details about how the gender dimension will be integrated must be provided in (1) the concept and (2) the methodology (see Annex B in this document). Those details should also appear in the summaries under general information.

  - Under the 'impact' criterion, proposals should address the sex- and gender-related targeted impacts as described in this document (Section 5.6). Regarding dissemination of project results, it should be clearly signalled to applicants that proposals that include sex and/or gender analysis are expected to report those findings in their peer-reviewed publications.

▶ For bottom-up work programmes (e.g. European Research Council, European Innovation Council and possibly calls relating to missions), applicants should be required to specify whether or not the gender dimension is relevant for their project. If so, applicants are to describe how sex and/or gender will be integrated into their project. If not, applicants are to briefly explain why sex and/or gender is not relevant to their proposed research.

Proposal evaluation and project reviewing

Under Horizon 2020, an evaluation of the proposed gender dimension is already part of all R & I actions and innovation actions under the 'excellence' criterion (concept and methodology), even for non-gender-flagged topics.

For Horizon Europe, we make the following recommendations.

▶ The evaluation of the quality of proposed gender dimension should extend beyond the 'excellence' criterion to also include the 'impact' criterion (see above under 'Proposal templates').

▶ An evaluation of the quality of the proposed gender dimension should be integrated into the current scoring system of 0–5, or receive a separate bonus point.

▶ Horizon Europe should develop criteria for scoring. For example, does the proposal have well-designed strategies

for data collection? Will data be properly disaggregated and analysed by sex and/or gender? Are sex, gender and/or intersectional factors carefully integrated into the research plan and properly analysed? Are there plans to report these results in peer-reviewed publications? For what to consider in these criteria, see Annex B in this document.

▶ Reviewers carrying out mid-term and final evaluations of funded projects should determine if the plans to include sex and/ or gender analysis have been effectively implemented.

▶ Gender experts in fields relevant to specific calls/topics should be included in evaluation panels, when possible. Gender experts should be invited by the European Commission to register in its database of experts annually. This database can be used by Commission staff to appoint evaluation panels. To facilitate this work, and for training purposes, the Commission might develop new AI tools to establish an interactive platform linked to the database to find gender expertise in different fields.

Dissemination and communication

▶ All materials developed by the Gendered Innovations Expert Group, such as briefing materials, infosheets, factsheets and evaluation criteria, as well as full case studies, methodologies and terms should be made available online to applicants, evaluators and reviewers, as well as to the wider public, including through:

- the online manual for Horizon Europe, accessible through the new European Commission Funding & Tenders Portal (replacing the Horizon 2020 Participant Portal);

- a section of the European Commission's Europa website dedicated to gender equality in R & I.

▶ A communication strategy has been developed by the expert group. This includes social media actions through European Commission-related Twitter accounts, the use of the infosheets and factsheets, and concepts for infographics and for a video. This strategy also illustrates how these policy recommendations for Horizon Europe support the implementation of the new European Commission gender equality strategy 2020–2025, e.g. the EU-wide communication campaign combating gender stereotypes, which will be launched by the European Commission to 'tackle all spheres of life with an intersectional approach and a focus on youth engagement, in collaboration with the Member States' (European Commission, 2020).

4. Monitoring and evaluation of Horizon Europe's policy on the gender dimension

▶ Project reporting templates should reflect the proposal submission templates by requiring reporting on integrating the gender dimension into the project's R & I content.

▶ Horizon Europe programme monitoring should include relevant indicators measuring the impact of the gender dimension in R & I content to demonstrate a return on R & I-funding investment.

- We recommend in particular the following regarding scientific impact.

  - Number and proportion of proposals for which sex and/or gender analysis receives the highest number of evaluation points, i.e. that are high-quality proposals. Many proposals will merely mention

sex and/or gender; these proposals will not result in scientific, social or economic impact and will not provide a return on investment. It is important to evaluate how many proposals employ sex and/or gender analysis by state-of-the-art methods.

- Number and proportion of topics that are negatively gender flagged in each work programme.

- Number and proportion of project-related peer-reviewed publications that include a gender dimension, as assessed from the list of output publications published on the European Commission Cordis website. This monitoring, which requires text mining for certain keywords, could be carried out in conjunction with the production of the *She Figures* publication (European Commission, 2019b), which includes an indicator on, and methodology for collecting, the number of publications integrating a gender dimension in their contents.

- Regarding societal impact, we recommend:

  - number and proportion of innovations, market opportunities, programmes or policies resulting from integrating sex and/or gender analysis into R & I;

  - number and proportion of innovations that can be classified as gender-sensitive.

- Regarding economic impact, we recommend:

  - number and proportion of R & I projects that support gender-inclusive economic transformations;

these programmes should also address intersections between gender and other social categories, such as abilities, LGBTI+ and ethnicity.

▶ Horizon Europe interim and final evaluations should specifically assess progress made on gender as a cross-cutting priority in Horizon Europe.

▶ Data from Horizon Europe monitoring processes and progress reports on integration of the gender dimension should be available:

- on the European Commission's Horizon Dashboard (accessible through the Funding & Tenders Portal (https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/horizon-dashboard)).

- in *She Figures*, which includes an indicator on, and methodology for collecting, the number of peer-reviewed publications integrating a gender dimension in their contents.

5. Organisational framework for integrating the gender dimension into Horizon Europe research and innovation contents

Effective integration of the gender dimension into R & I content in Horizon Europe requires enabling organisational structures within the European Commission and cooperation at the ERA level. This should include:

▶ a core structure within the DG R & I that coordinates the effective implementation of these policy recommendations into Horizon Europe, involving the DG R & I's Gender Sector and representatives from throughout the DG as well as from other

DGs and agencies concerned with Horizon Europe, where relevant;

▶ a body in the future ERA advisory structure that follows up on the current European Research Area and Innovation Committee Standing Working Group on Gender in Research & Innovation, consisting of delegates from Member States and Associated Countries to help implement the EU's policy on sex and/or gender analysis in research content;

▶ national contact points with gender expertise that can provide guidance, practical information and assistance on Horizon Europe's policies on integrating the gender dimension into R & I content, and can provide training at national level to research-funding organisations' policymakers, applicants, evaluators and staff;

▶ formal European cooperation building on the successful collaboration established between national research-funding organisations in several H2020-funded projects, and capitalising on the good practices developed by, for example, the Irish Research Council, the Research Council of Norway and the German Research Foundation.

6. Cluster- and mission-specific recommendations: targeted impacts

Each case study developed by the current expert group includes targeted impact-oriented recommendations for future R & I actions. Here is a guide for each Horizon Europe Pillar II cluster and mission.

Cluster-specific recommendations

Cluster 1: Health

These targeted impacts are drawn from the Gendered Innovations 2 Expert Group case studies 'Prescription drugs', 'Chronic pain', 'Systems biology', 'Agriculture', 'Extended virtual reality' and 'Facial recognition systems'.

Staying healthy in a rapidly changing society

Health and disease are strongly sex and gender related. Personalised and tailored solutions and advice can be achieved only when sex and gender are analysed in research aiming for personalised advice to promote health and prevent disease in individuals or for stratified solutions tailored to specific groups (see case study 'Systems biology').

Take account of the different health needs of women and men farmers and farm workers (some of whom may be foreign or seasonal). Analyse gender as it intersects with age, religion, race, ethnicity, socioeconomic status, geographical location, etc. (see case study 'Agriculture').

Tackling diseases and reducing disease burden

Sex-disaggregated data are essential for better surveillance, prevention, timely detection, treatment and crisis management of infectious disease threats, for example COVID-19 (see case studies 'Prescription drugs', 'Systems biology' and 'The impact of sex and gender in the COVID-19 pandemic').

Ensuring access to innovative, sustainable and high-quality healthcare

Gender aspects need to be considered when developing digital tools for medication regimens (e.g. apps to monitor diabetes therapy) that are managed by patients (see 'Co-creation

and participatory research' in Annex B). Special attention to the needs of rural populations is also required.

The use of FRSs in healthcare to identify and monitor patients is increasing. Take into consideration how these apps deal with gender, race/ethnicity, age and sexual orientation. Consider also that sex reassignment therapy may result in facial changes that may affect FRSs (see case study 'Facial recognition').

Unlocking the full potential of new tools, technologies and digital solutions for a healthy society

Novel tools and technologies for biomedical research, prevention, diagnosis and therapy will probably be driven by data and ICT. It is crucial that these source data be precisely annotated for sex and gender (see 'Analysing gender and intersectionality in machine learning').

Extended VR is increasingly used in healthcare to diagnose and manage patients with pain, disability, obesity, neurological dysfunction, anxiety and depression. Potential sex and gender differences need to be taken into account in the development and testing of prototypes.

Computer models and simulations aiming to understand health

Improving personalised medicine again requires that sex and gender data be collected and precisely annotated (see case study 'Systems biology').

Maintaining an innovative, sustainable and globally competitive health industry

Gender affects access to care globally, and incorporating this aspect may represent a unique selling proposition for companies. Decreased time to market must not mean reducing the variables tested, such as sex. Withdrawing a product from the market owing to lack of appropriate testing can damage companies (especially small and medium-sized enterprises, SMEs) permanently (see case study 'Prescription drugs').

Living and working in a health-promoting environment

Analyse occupational health risks in all genders. For farm workers, this includes attention to risky equipment and chemicals.

Cluster 2: Culture, creativity and inclusive society

These targeted impacts are drawn from the Gendered Innovations 2 Expert Group case studies 'Fair tax', 'Venture funding', 'Agriculture' and 'Extended virtual reality'.

Help reverse social, spatial, economic, cultural and political inequalities and their causes, and promote gender equality.

▶ Analyse how agricultural and rural transitions contribute to the social inclusion of marginalised groups by supporting their integration into researching, planning, implementing and monitoring. Include and address gender as it interacts with, for example, age, religion, race, ethnicity, socioeconomic status and geographical location.

▶ VR has been used in heritage sites such as museums, monuments and historical buildings. Without gender analysis, however, there is a risk that opportunities to foreground women's cultural heritage will be missed. VR provides an excellent opportunity to fill this gap (see case study 'Extended virtual reality').

▶ Promote and conduct research on fair taxation and ensure the availability of appropriate gender-disaggregated data. Further research is needed on the gender-differentiated distributional effects of net wealth, property taxes, inheritance taxes, value added taxes, excise taxes, corporate taxes, tax expenditures and gender-differentiated allocative effects of corrective taxes. Research should also address the compliance of tax measures

with legal gender equality obligations (see case study 'Fair tax').

- Ensure political commitment at the EU level[7] and define targets and indicators to achieve substantive gender equality with regard to taxation.

- Integrate a gender equality perspective into taxing for the future, combining social changes with an economy that works for people and a European Green Deal.

▶ Address gender bias in venture funding, business ownership and wages (this could also be supported under Pillar III, 'Innovative Europe', through the European Innovation Council).

- A first step is to analyse entrepreneurship for gender disparities in the venture funding sector and to ensure that stakeholders highlight and report on these disparities.

- A next step is to include women entrepreneurs in target groups in both the private and public sectors.

- A further step is to include gender equality demands in ownership and workforce in the public procurement of services and products (see case study 'Venture funding').

Cluster 3: Civil security for society

These targeted impacts are drawn from the Gendered Innovations 2 Expert Group case studies 'Facial recognition', 'Virtual assistants and chatbots', 'Quality urban spaces' and 'Agriculture'.

Disaster-resilient societies

Farmers can help prevent natural disasters; it is important to include gender differences in farmers' perspectives on risk management, prevention and actions (see case study 'Agriculture').

Protection of public space, security and resilience of infrastructure and vital societal functions, and fighting crime and terrorism

▶ Digital safety and security are important in terms of how digital assistants and chatbots handle data in relation to current laws (e.g. the General Data Protection Regulation[8]). Data that virtual assistants may have recorded in the home in times of crisis (e.g. domestic violence) may prove useful for law enforcement and provide vulnerable people with added security; however, take care to consider major ethical issues with extracting such data (see case study 'Virtual assistants and chatbots').

▶ AI may be recruited to better protect citizens from violent attacks in public spaces. FRSs are a new way of identifying criminals and terrorists. However, take care to implement proper design and ethical considerations so that facial recognition technology does not exacerbate existing gender and social inequalities (see case study 'Facial recognition').

▶ Public urban space and transportation, digital worlds and cyberspaces, and disaster and risk management should ensure the safety of women, men and gender-diverse individuals, of various ages and ethnicities. VR 'walkthroughs' in settings such as cities, parks and railway

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[7]   In line with the Resolution on gender equality and taxation policies in the EU, European Parliament (2018/2095(INI)).

[8]   Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation).

stations have been used to understand users' experiences in terms of how they decode the environment when considering personal safety (see case study 'High-quality urban spaces'). Since women, men and gender-diverse people tend to experience threats to personal safety differently, it is important to apply a user-driven approach that includes diverse groups of people. Moreover, homes as well as public spaces should be understood in terms of security and safety. Smart homes, for example, have been shown to pose certain threats to women.

▶ In rural areas, safety can be an issue because there is less formal policing. Violence constitutes a particular risk for rural women and gender-diverse individuals, as remote housing prevents effective formal or social control, and specialised social services are absent. Investigate and include these specific risks as well as prevention and resilience options.

Cluster 4: Digital, industry and space

These targeted impacts are drawn from the Gendered Innovations 2 Expert Group case studies on ICT: 'Extended virtual reality', 'Facial recognition' and 'Virtual assistants and chatbots'.

Key digital technologies

Digital assistants and chatbots have an important role to play in being inclusive and representative. Developers should take care not to reinforce gender stereotypes, e.g. by feminising chatbots.

Artificial intelligence and robotics

▶ Ensure that AI technologies and their benefits are accessible to all citizens and address a diversity of needs and preferences. For example, women are more than twice as likely as men to feel unwell from using VR, with symptoms such as pallor, sweating and general discomfort (see case study 'Extended virtual reality').

▶ In agriculture, digitalisation is becoming more important. Beyond automatisation through computers in warehouses, stables and milking parlours, the sector uses chips in animals, drones and self-driving tractors that are all connected to sensors, data processors and warning systems. Apply gender impact assessment to make sure gender-specific needs are taken into account (see 'Gender impact assessment' in Annex B).

Advanced computing and big data

▶ Ensure that AI and big data are free of gender bias. For example, wearing makeup can reduce the accuracy of facial recognition methods by 76 %; automatic gender recognition may not recognise transgender people, especially during transition periods; and FRSs perform better on men's than women's faces overall, and better on lighter than darker skin overall (see case study 'Facial recognition'). Carefully construct datasets to overcome these issues (see 'Analysing gender and intersectionality in machine learning' in Annex B). Data containing human information should include metadata summarising statistics on factors such as participant gender, sex, ethnicity, age and geographical location. Data labelling using crowdsourcing, such as MS Turk, should include information about crowd participants, along with the instructions given for labelling (see 'Analysing gender and intersectionality in machine learning' and 'Analysing gender and intersectionality in social robots' in Annex B).

▶ Employ AI and big data, where appropriate, to better understand gender-specific needs when designing products and services.

Cluster 5: Climate, energy and mobility

These targeted impacts are drawn from the Gendered Innovations 2 Expert Group case studies 'Smart energy solutions', 'Smart mobility', 'High-quality urban spaces' and 'Waste management'.

Advancing climate science and solutions for a climate-neutral and resilient society

R & I should consider:

- ▶ gender issues in access to energy, including energy poverty, analysed by age;

- ▶ the gender dimensions in transportation services and infrastructure, and women's, men's and gender-diverse individuals' needs in transportation (see case study 'Smart mobility');

- ▶ the gender dimensions in urban planning, including access to housing, employment and urban facilities, and ensuring the quality of public spaces (see case study 'High-quality urban spaces');

- ▶ creating digital solutions that are free of gender bias and omissions (see case studies on ICT, and 'Analysing gender and intersectionality in machine learning' in Annex B);

- ▶ gender and diversity aspects when identifying causes of and solutions for climate change, ensuring that analysis factors in behavioural and structural determinants so that solutions will be adopted by a majority of European people and economies;

- ▶ disaggregating all data by sex and/or gender;

- ▶ analysing gender and diversity when developing climate services and decision-support tools and methodologies;

- ▶ disaggregating data by sex and/or gender when assessing impacts;

- ▶ employing gender impact assessments in agriculture and natural resource management sectors in order to avoid exacerbating inequalities when decarbonising the EU's economy and developing a fully circular economy.

Developing sustainable infrastructure, services and systems for smart and sustainable communities and cities

Consider the following suggestions.

- ▶ Employ co-creation and participatory research that include end-users when developing improved technologies, services and business models. Analysis should include attention to gender, age and socioeconomic status so that solutions appeal to users in their individual contexts (see case study 'Smart energy solutions', and 'Co-creation and participatory research' in Annex B).

- ▶ Employ co-creation and participatory research when developing methods of citizen engagement in energy and transport investment and transition policies. This research must understand what motivates citizens to participate or invest time and/or money in this work.

- ▶ Encourage citizen science or user-led innovation to engage in gender-sensitive and intersectional data collection, development and testing procedures to ensure greater acceptance of these solutions.

Empowering citizens to engage in the transformation to a decarbonised society

▶ Prioritise changing minds and behaviours to mitigate climate challenges. VR has proven successful in enhancing empathy and moving people to action. For example, studies have shown that VR exposure to climate issues, such as the negative effect of CO_2 emissions, has influenced travel-related decisions. Such programmes require intersectional analysis (e.g. analysing how gender intersects with economic status and geographical location) (for similar uses of VR, see case study 'Extended virtual reality').

▶ Equip chatbots and digital assistants with excellent information about climate and energy issues. Digital assistants can be used, for example, to provide sustainable transport options (see case study 'Virtual assistants and chatbots').

▶ Consider gendered issues in waste management. Gendered knowledge can contribute to better solutions for city/district management of waste systems and contribute to meeting EU-wide low-carbon goals (see case study 'Waste management'). Employing co-creation and co-design can empower all citizens to engage in these transformation processes (see 'Co-creation and participatory research' in Annex B).

Developing low-carbon and competitive transport solutions in all modes

▶ Consider the gender dimensions in mobility needs and behaviour when designing mobility services and infrastructure.

▶ Develop gender-sensitive digital solutions that enhance access for all.

▶ Make gender analysis central to the systemic transformation of transport and mobility (see case study 'Smart mobility').

Cluster 6: Food, bioeconomy, natural resources, agriculture and environment

These targeted impacts are drawn from the Gendered Innovations 2 Expert Group case studies 'Agriculture' and 'Marine science'.

Environmental observation

Sex as a biological variable must be incorporated as a key component of environmental models that seek to determine species' sensitivity to climate change and species interactions. Only such models can be used for evidence-based policy (see case study 'Marine science').

Biodiversity and natural capital

▶ Research drivers of biodiversity loss. Analyse sex as a factor determining species' sensitivity to stressors (see 'Analysing sex' and 'Analysing sex in hermaphroditic species' in Annex B).

▶ Effective communication and dissemination activities are critical to raising societal awareness. Sex analysis in the context of climate change provides an intriguing and novel key message highlighting the differential sensitivity of female and male marine species to climate change, the impact of climate change on sex determination and differentiation, and the role sex plays in population sensitivity. Examples that resonate with the public can inspire action.

Seas, oceans and inland waters

▶ Understanding, forecasting and monitoring changes within seas, oceans and inland waters will require analysing biological sex in marine organisms as a factor determining sensitivity. This includes disaggregating all results by sex (see case study 'Marine science', and 'Analysing sex in hermaphroditic species' in Annex B).

▶ Sex analysis in marine organisms should become an integral component of robust world-class climate change science and must be incorporated into research, education, and environmental management and policy.

Food systems

▶ The success of the European Green Deal in the agricultural and food sector depends on the contribution of all rural residents – across all genders, ages, nationalities, cultures, etc. The active engagement of all citizens is needed to address the influence of gender norms in these sectors (see case study 'Agriculture').

▶ Analyse gendered approaches to waste management to support the food system by lowering food waste and decreasing the burden of food packaging.

Mission-specific recommendations

Sex and/or gender analysis in R & I content is almost completely absent from the five interim mission reports/outlines released on 25 June 2020, which were developed by the Horizon Europe mission boards, save for two mentions of sex/gender as determinants, in the cancer mission outline, and a reference to training and up-skilling a new gender-balanced blue workforce, in the outline of the mission on healthy oceans, seas, coastal and inland waters. Such omissions can lead to failed science. Integrating sex and/or gender analysis along with intersecting categories, such as ethnicity and socioeconomic status, adds value to R & I in terms of excellence and creativity. Incorporating the gender dimension also enhances equality by ensuring that findings and innovations apply to all citizens and society as a whole.

Mission area: cancer – 'Conquering cancer: mission possible'

On the Mission Board, include representatives from groups with sex and gender-specific knowledge, such as the Gender in Oncology task force of the European Society for Medical Oncology (ESMO). To ensure equal access and benefits to all European patients and citizens, sex and gender must be considered in cancer studies, cancer data analysis and modelling of treatments.

Data

▶ Sex is an important biological variable. All data collection and reporting must be sex-disaggregated to facilitate future meta-analyses.

▶ Gender is an important cultural variable. All data collection and reporting must be gender-disaggregated to facilitate future meta-analyses.

▶ If big data and machine learning techniques will be employed for low-cost population risk prediction, sex/gender bias in the source data needs to be investigated and corrected for.

▶ Polygenic risk score development needs to be based on sex-disaggregated data and possibly lead towards gender-sensitive risk counselling.

Prevention

▶ Cancer prevention strategies should be gender-sensitive. This applies to the screening location (e.g. workplace versus primary care physician), delivery of information and facilitation of healthy lifestyle choices.

Diagnosis

▶ Gender-specific barriers to access to early diagnostic and minimally invasive treatment technologies need to be removed in all EU Member States.

- XR technologies are increasingly used for diagnosing and managing patients. These technologies may improve women's health, for example by aiding early diagnosis of breast cancer or managing the symptoms of menopause.

Treatment

- The proposed European Cancer Patient Digital Centre needs to be equally accessible to all citizens, transcending possible inequalities in digital literacy. Sex- and gender-specific risk factors should be recorded.

- The future network of comprehensive cancer infrastructures needs to include expertise on sex/gender in oncology.

- Innovation and implementation of new technology in the field of cancer need to be gender-sensitive to guarantee equal access and benefit for all.

Quality of life

- Quality-of-life (QoL) measurements of patients, survivors, family members and carers need to be gender-sensitive. Cancer may affect the QoL of women, men and other genders differently, which needs to be considered for optimal support.

Pain

- The prevention of chronic pain related to cancer should integrate sex analysis into treatments and develop gender-sensitive approaches to pain management.

- Pharmacological pain management needs to be gender-sensitive and sex-specific to improve patients' outcomes and QoL.

Personalised treatment

- Personalised medicine approaches for cancer need to be sex-specific and gender-sensitive to ensure equal access and benefits for all patients.

Mission area: adaptation to climate change, including societal transformation – 'Accelerating the transition to a climate-prepared and resilient Europe'

- To enhance efficiency in the energy sector, integrate gender-sensitive and intersectional approaches into all aspects of research, including:

  - the behaviours and expectations of users with respect to energy use and energy technologies;

  - the impact of energy-related technologies, products, services and policies; diverse user groups can have diverse needs that must be taken into account in order to provide products, services and solutions that are adapted to those needs, and to provide products, services and solutions that will be widely accepted and implemented;

  - targets and action plans.

- Consumers should be actively involved in the R & D, design and testing.

Mission area: healthy oceans, seas, coastal and inland waters – 'Regenerating our ocean and waters by 2030'

- Key factors determining species extinction in the face of climate change are population stability, sex ratios and the sensitivity of males and females. Incorporating sex analysis is therefore vital to accurately understand the threat of climate change (and other environmental stressors such as pollution) on marine organisms, and thus to effectively establish robust mitigation strategies.

- Sex must be analysed in the context of biodiversity loss and safeguarding life on Earth.

- Understanding, forecasting and monitoring changes within seas, oceans and inland waters requires the inclusion of sex as

a factor determining sensitivity at all levels of experimentation, modelling and mitigation.

▶ Conservation of marine stocks could increase the annual profits of the seafood industry by EUR 49 billion. Sex analysis is shown to be a key factor for ensuring effective population management of marine organisms.

Mission area: climate-neutral and smart cities – '100 climate neutral cities by 2030 – by and for the citizens'

The June 2020 interim report on this mission (European Commission, 2020b) emphasises that cities can achieve climate neutrality only if citizens become agents of change through bottom-up initiatives and innovation and through new forms of governance. It declares that holistic and transformative missions aiming to create climate-neutral cities, based on citizens' participation and social inclusiveness, can help the EU progress towards achieving multiple SDGs, including equality. The Climate City Contract (CCC) will need to ensure that gender issues are an explicit part of designing and implementing these transformation processes.

This includes:

▶ considering the specific needs of women, men, girls, boys and gender-diverse individuals across age groups, socioeconomic classes and abilities;

▶ ensuring that small towns are included – in this context, it is important to analyse gender differences in access, resources, affordability and connectedness;

▶ a gendered approach to better understand citizen behaviours, attitudes and potential engagement in minimising resource inputs, waste and carbon emissions in a circular economy;

▶ analysing how women, men, girls, boys, and gender-diverse people use cities differently; quality streets and public spaces must respond to the different daily needs of people, and particularly of children, the elderly and their caregivers.

Mission area: soil health and food – 'Caring for soil is caring for life'

Humans

▶ Consider a gender-sensitive approach to new programmes to overcome bias and allow representation of specific interests, experiences and knowledges. Rural and gender impact assessments of programmes can identify potential exclusion patterns and ways to redress them upfront.

▶ Protect tangible and intangible agricultural cultural heritage produced by women, men, and gender-diverse individuals, and ensure its transfer. Examples include traditions and rituals, handicrafts, music and dances, food cultivation, wild food gathering, herbal medicines, storage and preservation techniques, and meal preparation. Connect heritage practices, where appropriate, to rural and agricultural transition challenges, health support systems, economic growth and mobility (entrepreneurship in tourism, rural business), and civil security in rural areas.

Biodiversity

▶ Research drivers of biodiversity loss: analyse sex as a factor determining species sensitivity to stressors.

Animals

▶ Bring sustainable and innovative solutions to tackle infectious animal diseases. Sex is a key factor determining the susceptibility of animals to disease-causing agents. Incorporating sex analysis is thus an important consideration for a partnership on animal health and infectious disease.

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6. MEMBERS OF THE EXPERT GROUP

The H2020 Expert Group to update and expand Gendered Innovations / Innovation through Gender (E03601) (European Commission, n.d.) (Gendered Innovations 2 Expert Group) was created in December 2018. It kicked off its activities in a first workshop organised on European Commission premises in Brussels by the DG R & I's Gender Sector, on 18–19 March 2019. Two more expert group workshops took place in Brussels, on 1–2 July 2019 and 25–26 November 2019.

List of contracted experts

Role in expert group	Name and affiliation	Country
Chairperson	**Londa Schiebinger** Professor of History of Science, Stanford University	US
Rapporteur	**Ineke Klinge** Professor of Gender Medicine; President, Dutch Society for Gender and Health	NL
Subgroup 1: **Methodology and conceptualisation**	**Mathias Wullum Nielsen** (Lead) Associate Professor, Department of Sociology, University of Copenhagen	DK
	Anke Lipinsky Senior researcher, Centre of Excellence Women and Science (CEWS), GESIS – Leibniz Institute for the Social Sciences	DE
	Petr Pavlik Professor, Department of Gender Studies, Faculty of Humanities, Charles University, Prague	CZ
	Sabine Oertelt-Prigione Strategic Chair of Gender in Primary and Transmural Care, Radboud University, Nijmegen (also Lead of subgroup 2)	NL
Subgroup 2: **Health, neuroscience, food**	**Sabine Oertelt-Prigione** (Lead) Strategic Chair of Gender in Primary and Transmural Care, Radboud University, Nijmegen (also in subgroup 1)	NL
	Carole Clair Associate Professor, Gender and Medicine Unit Centre for Primary Care and Public Health, Lausanne University	CH
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In addition to these 25 experts, four invited independent experts participated and contributed to this expert group:

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ANNEXES

ANNEX A – FIFTEEN FULL CASE STUDIES

Health

PRESCRIPTION DRUGS: ANALYSING SEX AND GENDER

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The challenge

Historically, drug development has followed a 'one size fits all' model. Drug testing has been conducted predominantly on males, from pre-clinical research in rodents to clinical trials that include few women (Mazure and Jones, 2015). As a result, women report more unwanted, and sometimes deadly, side effects than men. In the late 1990s, 10 drugs were withdrawn from US markets. Of these, eight showed greater health risks for women (US General Accounting Office, 2001).

Gendered innovation 1:
Including females and males in all stages of drug development

Female and male bodies metabolise drugs differently. For example, female bodies tend to take longer to digest food and to expel waste through their kidneys. Female and male livers process proteins and other molecules at different speeds (Franconi and Campesi, 2014). Because female-typical and male-typical bodies process drugs at different speeds, people with female-typical bodies may be at higher risk of side effects and overdose than people with male-typical bodies (Freire et al., 2011). In a recently published study, researchers reported that 76 out of the 86 drugs investigated displayed higher concentrations in female-typical bodies (Zucker and Prendergast, 2020). This was not explained by differences in body size, but seems to relate to complex physiological differences.

The two main types of medications are small molecules (that bind to receptors in the body) and biologics (proteins, antibodies and other substances already found in humans). Small molecules may have sex-specific pharmacokinetics (how the body metabolised the drug) and pharmacodynamics (how the drug affects the body; see Figure 1). Female-typical bodies and male-typical bodies may also respond differently to biologics, since the production and function of immune cells and antibodies can be affected by an individual's sex chromosomes and levels of oestrogens and androgens.

Women tend to have smaller body size and more fat tissue than men, which affects drug distribution, and smaller kidneys, which leads to slower drug elimination. Liver enzymes may behave differently because of oral contraception and some hormone therapy. Women's heart rhythms are different from men's (longer QT interval), which makes women more susceptible to fatal heart disturbances, called arrhythmias. © Sabine Oertelt-Prigione

If female cells and animals are not included in the early phases of drug development, sex-specific differences in efficacy and toxicity will not be detected. And, if women are not included in clinical trials, the real-world effects of a medicine will not be detected before it is released to the market.

Recognising these problems, the United States created the Food and Drug Administration Office of Women's Health (FDA-OWH) in 1994

SEX DIFFERENCES IN DRUG PROCESSING

IN WOMEN	PHYSIOLOGICAL DIFFERENCES		IN MEN
Body Composition			
SLOWER PROCESSING OF MOST DRUGS	⬆ Fat Mass ⬇ Lean Mass	⬇ ⬆	FASTER PROCESSING OF MOST DRUGS
MORE ACCUMULATION OF LIPOPHILIC DRUGS	⬆ Free Water	⬇	LESS ACCUMULATION OF LIPOPHYLIC DRUGS
DIFFERENT CONCENTRATIONS OF HYDROPHILIC DRUGS (ALSO THROUGHOUT THE MENSTRUAL CYCLE)			DIFFERENT CONCENTRATIONS OF HYDROPHILIC DRUGS
HIGHER RESTING HEART RATE	⬆ Heart Rate Variation	⬇	LOWER RESTING HEART RATE
LONGER QT INTERVALS			SHORTER QT INTERVALS
HIGHER RISK OF ARRHYTHMIAS			LOWER RISK OF ARRHYTHMIAS
SLOWER ABSORPTION OF DRUGS	⬇ Gastric Motility	⬆	FASTER ABSORPTION OF DRUGS
DIFFERENT EXPRESSION OF CYTOCHROME P450 (E.G. CYP3A4 MORE IN WOMEN)	⬇ Stomach Acidity	⬇	DIFFERENT EXPRESSION OF CYTOCHROMES p450 (CYP; E.G. CYP2D6 AND CYP2E1 MORE IN MEN)
ESTROGENS AND PROGESTERONE COMPETE WITH DRUGS FOR DEGRADATION BY CYP450	Liver Enzymes		
SLOWER EXCRETION OF DRUGS	⬇ Kidney Excretion	⬆	FASTER EXCRETION OF DRUGS
SLOWER ELIMINATION OF DRUGS	⬇ Colon Motility	⬆	FASTER ELIMINATION OF DRUGS

Women tend to have smaller body size and more fat tissue than men, which affects drug distribution, and smaller kidneys, which leads to slower drug elimination. Liver enzymes may behave differently because of oral contraception and some hormone therapy. Women's heart rhythms are different from men's (longer QT interval), which makes women more susceptible to fatal heart disturbances, called arrhythmias. © Sabine Oertelt-Prigione.

to advocate women's inclusion in clinical trials (Obias-Manno et al., 2007). The 1993 US NIH Revitalization Act also mandates the inclusion of women and minorities in clinical trials (Mastroianni et al., 1994). Despite these important steps, female cells, animals and human participants are still not properly included in all stages of the drug development process. The *British*

Journal of Pharmacology recommends that all future studies either include both sexes in the experimental design or explain why researchers believe sex and gender are not relevant (Docherty et al., 2019). Other journals and funding agencies have developed similar policies to promote sex analysis in drug development (Schiebinger et al., 2011–2020).

Method: analysing sex in tissues and cells

Female and male cells are affected by their sex chromosomes and by the hormonal influences in their environment. Furthermore, certain types of cells, e.g. liver cells, produce different amounts of metabolic enzymes. If sex differences are not taken into account, experimental results will probably be irreproducible. Analysing the cell response to medication in a sex-specific manner can offer early indications of potential differences that should influence the drug development process (Docherty et al., 2019).

Gendered innovation 2:
Disaggregating side effect reporting by sex

Women experience more unwanted drug side effects than men (Spoletini et al., 2012). The magnitude of the problem, however, is difficult to quantify because, historically, countries have not included sex information in their statutory reports of side effects.

New reporting guidelines, such as Prisma-Equity Extension (Welch et al., 2012) and Consort-Equity 2017 (Welch et al., 2017), advocate the reporting of data disaggregated by sex. These guidelines (in addition to more stringent journal reporting requirements noted above) have significantly increased the availability of sex-disaggregated data needed for large comparative studies and for meta-analyses aimed at predicting unwanted side effects better.

Gendered innovation 3:
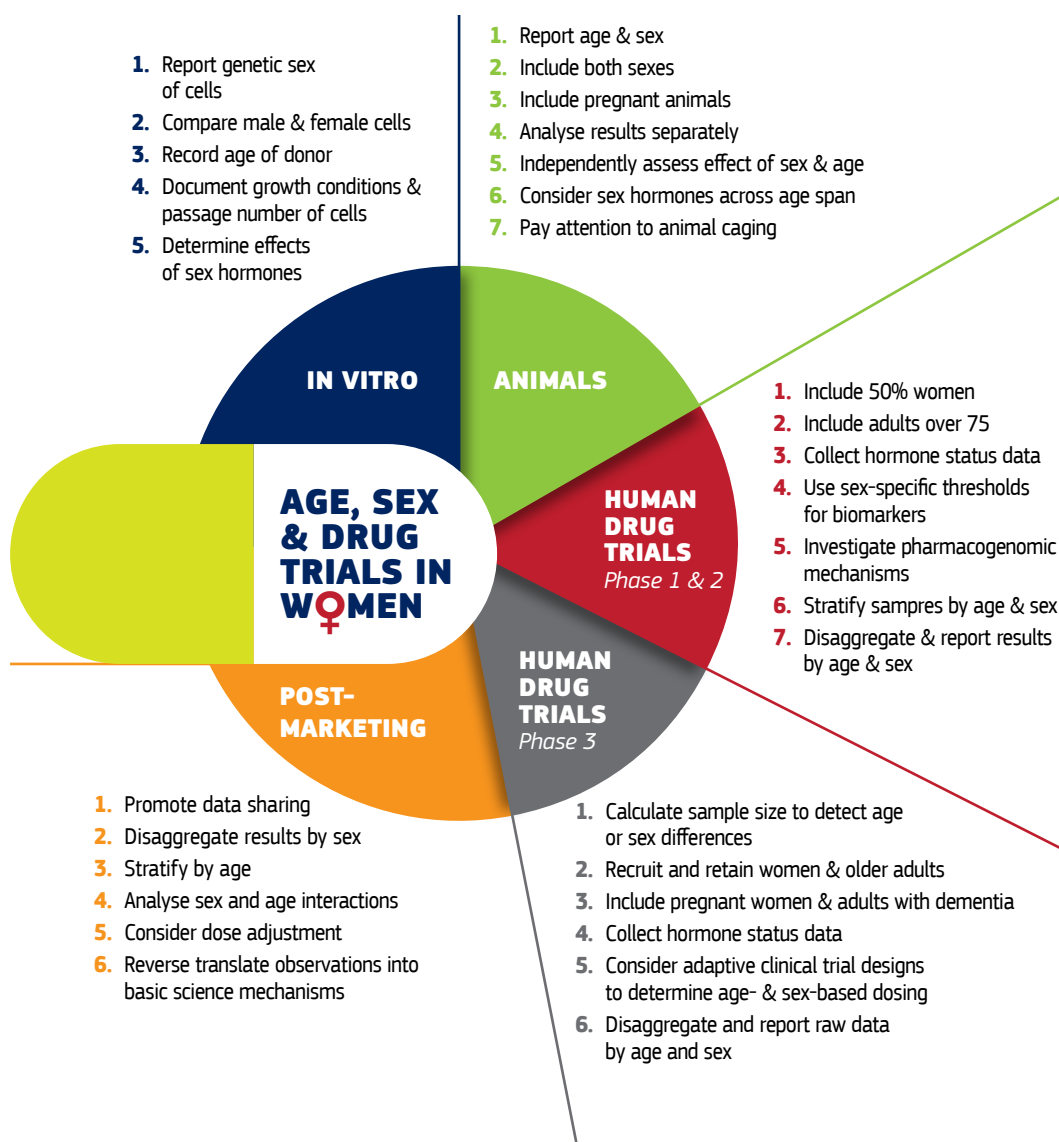**Reporting sex differences on drug labels**

Some medication already has sex-specific dosing. Take, for example, the drug desmopressin, which activates vasopressin receptors in the kidney to regulate water homeostasis (Juul et al., 2011). Women have been found to be more sensitive to the antidiuretic effects of vasopressin than men. This may be because the gene for the arginine vasopressin receptor is found on the X chromosome in a region likely to escape X-inactivation. Males have only one X chromosome and therefore only one copy of the vasopressin receptor gene per cell; females are more likely to have two copies. As a result, older women taking desmopressin are most likely to experience a reduction of sodium concentration, leading to side effects such as weakness, dizziness and fainting. To avoid unnecessary harm, both the EU and Canada have recommended lower dosages of desmopressin for older women. The drug is consequently marketed with different recommended doses on the labelling package for women and men.

Research on biologics shows that these new treatments can also have sex-specific effects. For instance, the EU-funded Abirisk study found sex and age differences in the production of antidrug antibodies to biologics developed for the treatment of multiple sclerosis (Bachelet et al., 2016). Similarly, patients with melanoma and lung cancer responded differently to checkpoint inhibitor drugs based on their sex. A higher proportion of male than female patients achieved successful remission, depending on the type of biologic used (Conforti et al., 2018). Designed to outsmart cancer cells' defence tactics, checkpoint inhibitors stimulate natural killer immune cells to attack tumour cells. Natural killer cells are sensitive to oestrogen and testosterone, which may explain the observed sex differences (Giefing-Kröll et al., 2015). The Gender difference in side effects of immunotherapy project (G-Definer, 2020), funded through the Horizon 2020-supported GENDER-NET Plus ERA-NET Cofund, is currently studying the existence of sex-driven differences in immune responses as potential factors contributing to disease outcome and response to immunotherapy.

Method: analysing sex

Females and males must be included in all drug trials – from early cell and animal testing to human clinical trials – and analysed separately (Tannenbaum et al., 2017). Age and genetic ancestry should also be considered, as these characteristics may affect drug efficacy, safety and toxicity (Dandara et al., 2014). Pregnancy also requires attention, as pregnant women become ill and ill women become pregnant. Information about drug safety effects on the foetus is a priority.

IN VITRO

1. Report genetic sex of cells
2. Compare male & female cells
3. Record age of donor
4. Document growth conditions & passage number of cells
5. Determine effects of sex hormones

ANIMALS

1. Report age & sex
2. Include both sexes
3. Include pregnant animals
4. Analyse results separately
5. Independently assess effect of sex & age
6. Consider sex hormones across age span
7. Pay attention to animal caging

AGE, SEX & DRUG TRIALS IN WOMEN

HUMAN DRUG TRIALS *Phase 1 & 2*

1. Include 50% women
2. Include adults over 75
3. Collect hormone status data
4. Use sex-specific thresholds for biomarkers
5. Investigate pharmacogenomic mechanisms
6. Stratify sampres by age & sex
7. Disaggregate & report results by age & sex

POST-MARKETING

1. Promote data sharing
2. Disaggregate results by sex
3. Stratify by age
4. Analyse sex and age interactions
5. Consider dose adjustment
6. Reverse translate observations into basic science mechanisms

HUMAN DRUG TRIALS *Phase 3*

1. Calculate sample size to detect age or sex differences
2. Recruit and retain women & older adults
3. Include pregnant women & adults with dementia
4. Collect hormone status data
5. Consider adaptive clinical trial designs to determine age- & sex-based dosing
6. Disaggregate and report raw data by age and sex

Sex and age considerations in drug development and testing. Source: Tannenbaum et al. (2017), With permission.

Gendered innovation 4:
Promoting gender–transformative treatment approaches

Gender–transformative approaches address the causes of gender-based inequities and seek to transform harmful gender norms, roles and relations (WHO, 2011). Consider that antianxiety and antidepressant drugs are prescribed more frequently to women, even though men are more likely to commit suicide. Is it because women behave differently, seeking healthcare services more often? Or do gender norms dictate how women and men are socialised to express feelings and emotions? Do the screening tools prescribers use to detect symptoms exhibit gender bias, preferentially asking about crying and helplessness? The result is a prescription regime that differs not only by sex but as a result of gender norms, behaviours and relations (Rochon et al., 2018). Raising awareness about gender bias in the expression of symptoms, screening questions and patterns of prescribing will help prevent harm.

Gender bias in prescribing can affect men and women. Older women are more likely to receive inappropriate prescriptions both because of age and sex differences in pharmacokinetics and because of gendered patterns in prescribing (Tannenbaum et al., 2009; Morgan et al., 2016; Sramek et al., 2016). This is especially true among women diagnosed with dementia (Moga et al., 2017). Sometimes, however, the situation is reversed: when taking antipsychotic medication for the first time, subsequent hospitalisation and death rates among men with dementia exceed those in women. The use of antipsychotic and other medications can rapidly lead to the prescription of a second medication to treat the side effects of the first drug: a prescribing cascade. To help prevent prescribing cascades, sex and gender differences need to be understood. This is the aim of the project Identifying key prescribing cascades in the elderly (iKascade), funded by GENDER-NET Plus (n.d.), which is evaluating how men and women may react to an adverse event differently and to what extent they fall victim to prescribing cascades.

Once gender bias is recognised, solutions should be implemented to narrow gaps in adverse outcomes (Tannenbaum et al., 2016). In the case of heart disease, it is well known that women experience symptoms of heart attack differently from men, leading to underdiagnoses in women (see case study 'Heart disease in diverse populations'). To redress this inequity, emergency physicians developed a four-step gendered protocol to bypass many of the gender biases in symptoms, testing, diagnosis and access to treatment (Huded et al., 2018). The study found that this protocol, coupled with improved access to treatment, cut mortality rates for women in half.

> **# Method: analysing gender in biomedicine and health**
>
> Gender stereotypes can affect clinical care in several ways. First, gender and age bias can affect the diagnostic questions asked to detect health conditions (Sheehan and Tucker-Drob, 2017; Verdam et al., 2017). Physicians and researchers should pay attention to language and gender norms in diagnostic procedures. Second, gender relations between the healthcare provider and the patient can affect prescribing patterns and treatment outcomes (Greenwood et al., 2018; Rochon et al., 2018). Age and race can also play a role.

Conclusions

Addressing sex and gender in drug prescribing can start with relatively simple yet powerful steps, from including female and male cells, tissues and organisms throughout the testing process to reporting all data disaggregated by sex. These approaches will provide the knowledge needed to develop sex-specific dose adaptations of existing drugs, such as desmopressin or zolpidem, and may lead to sex-specific treatments in the future. Physicians, pharma-

cists and patients should consider gender differences in how symptoms are experienced and expressed. What is reported and how it is reported affect which diagnostic steps occur and which medications are prescribed.

>> **Next Steps**

Accelerating these developments needs the following steps.:

1. Regulatory agencies should require (not simply recommend) sex-disaggregated reporting of all drug trial results by the pharmaceutical industry. Regulatory agencies should also ensure that sex-specific information is available to prescribers and patients on websites and drug labels.

2. Post-marketing surveillance studies should aim to detect sex-specific side effects and differences in response. Many pharmaceuticals currently on the market were tested and approved in years when women were excluded from clinical trials. Post-marketing surveillance is the only way to obtain data on sex differences in efficacy and toxicity in these drugs.

3. Researchers and physicians should further investigate gendered norms, identity and relations in medical communication and prescription outcomes.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Cluster 1: Health

Staying healthy in a rapidly changing society

- Medicines need to be more extensively tested in pregnant women (with safety as the first goal).

- Citizens need to be able to trust that the medicines they are taking are safe for everyone, that citizens are protected from inappropriate medicines, and that therapies are sufficiently tested in women, men and gender-diverse individuals, taking into account other intersecting factors, such as age and ethnicity, where relevant.

- Health literacy needs to be promoted in all patients to increase informed health decision-making.

Tackling diseases and reducing disease burden

- Effective, cost-efficient and affordable treatment needs to be made available to all patients: women, men and other genders (taking into account other intersecting factors, such as age and ethnicity, where relevant).

- Strengthen expertise in sex-sensitive and gender-sensitive R & I in order to guarantee the excellence, inclusion and reach of the products developed.

- Diagnostics need to be tested for sex and gender sensitivity and specificity.

- Sex-disaggregated data are essential for the better surveillance, prevention, detection, treatment and crisis management of infectious disease threats.

Ensuring access to innovative, sustainable and high-quality healthcare

▶ A shift from hospital-based to community-based care needs to take gender dynamics into account.

▶ Healthcare leadership needs to be representative of social diversity. This will improve the ability to understand healthcare problems, find targeted and patient-centred solutions, and foster patient empowerment.

▶ The gender-related digital divide among healthcare professionals, e.g. in the nursing profession, needs to be addressed to guarantee quality and to ensure job retention.

▶ Gender aspects need to be considered in the development of digital tools to accompany medication regimens that are managed by patients (e.g. apps to monitor diabetes therapy).

▶ A holistic approach to health policy and systems requires a gender-sensitive intersectional approach.

Unlocking the full potential of new tools, technologies and digital solutions for a healthy society

▶ To be innovative and world-class, healthcare must be sex-sensitive and gender-sensitive.

▶ Bias in AI solutions due to the sex bias in datasets (former and newly acquired) is a priority that needs to be addressed.

▶ Gender impact assessments of new AI solutions for drug targeting (and many other functions) should be mandated.

▶ Legal, regulatory and ethical frameworks need to consider gender inequalities in access and therapy, as well as sex and gender bias in the knowledge base used to develop innovative solutions.

▶ Co-creative approaches to health solution design need to include diverse patient and user groups.

Maintaining an innovative, sustainable and globally competitive health industry

▶ For the EU health industry to be competitive internationally, solutions need to be diversified to reflect an international market. Gender affects access to care in parts of the world beyond the EU, and incorporating this aspect may represent a unique selling proposition for companies.

▶ Decreased time to market must not mean reducing the variables tested. Sex differences affect product efficacy in potentially 50 % of the population; withdrawing a product from the market owing to lack of appropriate testing can damage companies (especially SMEs) permanently.

Mission area: cancer

Since pharmacotherapy is a cornerstone of cancer therapy, all the considerations noted above for drug development apply to this mission. Furthermore, AI technologies are increasingly being used to diagnose cancer and identify viable therapeutic options. For these fields the considerations formulated for AI are highly significant.

▶ The proposed European initiative to understand cancer (UNCAN.eu) should ensure that all data collected will be sex-disaggregated and all results reported in a sex-disaggregated manner to facilitate future meta-analyses.

▶ Polygenic risk score development needs to be based on sex-disaggregated data and possibly lead to gender-sensitive risk counselling.

▶ Cancer prevention strategies should be gender-sensitive. This applies to the screening location (e.g. workplace versus primary care physician), delivery of information and facilitation of healthy lifestyle choices.

- If big data and machine learning techniques will be employed for low-cost population risk prediction, inherent sex/gender bias in the source data needs to be investigated and corrected for.

- Personalised medicine approaches for cancer need to be sex-specific and gender-sensitive to ensure equal access and benefits for all patients.

- Gender-specific barriers to access to early diagnostic and minimally invasive treatment technologies need to be removed in all EU Member States.

- QoL measurements of patients, survivors, family members and carers need to be gender-sensitive, calibrated according to differences in the general population and differentiated according to the dimensions of QoL. The impact of cancer on QoL might affect different domains in women, men and other genders. This needs to be considered for optimal support.

- The proposed European Cancer Patient Digital Centre needs to be equally accessible to all citizens, transcending possible inequalities in digital literacy. Sex- and gender-specific risk factors should be recorded.

- The future network of comprehensive cancer infrastructures needs to include expertise on sex/gender in oncology.

- Innovation and implementation of new technology in the field of cancer needs to be gender-sensitive to guarantee equal access and benefit for all.

- Person-centred care has to be gender-sensitive, patient participation should be equitable and include intersectional groups of women, men and other genders living with cancer.

- Sex- and gender-specific knowledge should be aggregated through expert committees for the mission board, such as ESMO's Gender in Oncology task force.

Partnerships on health

EU–Africa partnership on health security to tackle infectious diseases

- Focus on the sex- and gender-specific impacts of zoonoses and emerging and existing infectious diseases. Socioeconomic and logistic factors need to be considered alongside biological mechanisms of infection.

- Ensure gender-balanced representation of researchers in each country involved, and diversity of thematic approaches and methodologies.

Innovative health initiative

- Ensure equal representation of interests and priorities among diverse stakeholder networks.

- Innovation should include a social, economic and cultural dimension in addition to its technical goals.

European partnership for chemicals risk assessment

- Sex-specific aspects of exposure and metabolisation of chemicals should be addressed.

- The impact of gender on exposure, detection and protection should be considered.

Large-scale innovation and transformation of health systems in digital and ageing society

- Include a focus on sex and gender in the innovation process. Dissect the needs of ageing women, men and individuals of other genders to ensure needs-driven innovation options.

- Investigate intrinsic biases in current health systems against women, other genders, ethnic minorities and socially disadvantaged individuals. Apply the results to develop socially impactful solutions.

Personalised medicine

▶ Avoid limiting the focus on solely biological and omics data when proposing preventative, diagnostic and therapeutic solutions. Social factors, e.g. gender, socioeconomic status and discrimination, can modify epigenetic and metabolic markers. These variables also affect access to personalised medicine and should be accounted for.

Rare diseases

▶ Gendered aspects in the networks of care of people living with rare diseases should be analysed.

▶ Although complex statistics are limited by sample size, descriptive statistics should always report sex-specific data.

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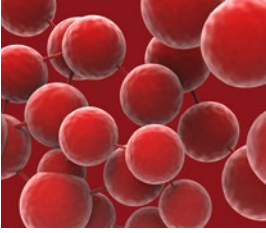
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SYSTEMS BIOLOGY: COLLECTING SEX- AND GENDER-SPECIFIC DATA

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The challenge

Systems biology is the computational and mathematical modelling of complex biological systems. It is an interdisciplinary field of study that focuses on complex interactions within biological systems (Tavassoly et al., 2018). Systems biology lets us understand how interactions among multiple components form functional networks at the organism level. For example, Tareen et al. (2019) used systems biology to identify a molecular switch that tissues use to rely either on glucose or on fatty acids as fuel. Systems biology also develops computational predictive models of disease that will transform disease taxonomies from phenotypical to molecular and will enable personalised/precision therapeutics (Bielekova et al., 2014). Systems biologists often use omics data (genomics, transcriptomics, proteomics, metabolomics) to provide broad insight into the molecular dynamics that accompany genetic, cultural, ethnic and societal influences on a living organism. For example, a high daily intake of fat (related to cultural and societal factors) has a negative influence on the metabolic performance of tissues in the body and increases the risk of type II diabetes. Systems biologists use omics data to understand a tissue's metabolic status over time. Since there is sex and gender bias in omics data, current biological models mainly apply to cisgender men, whereas models of other bodies and genders are underrepresented.
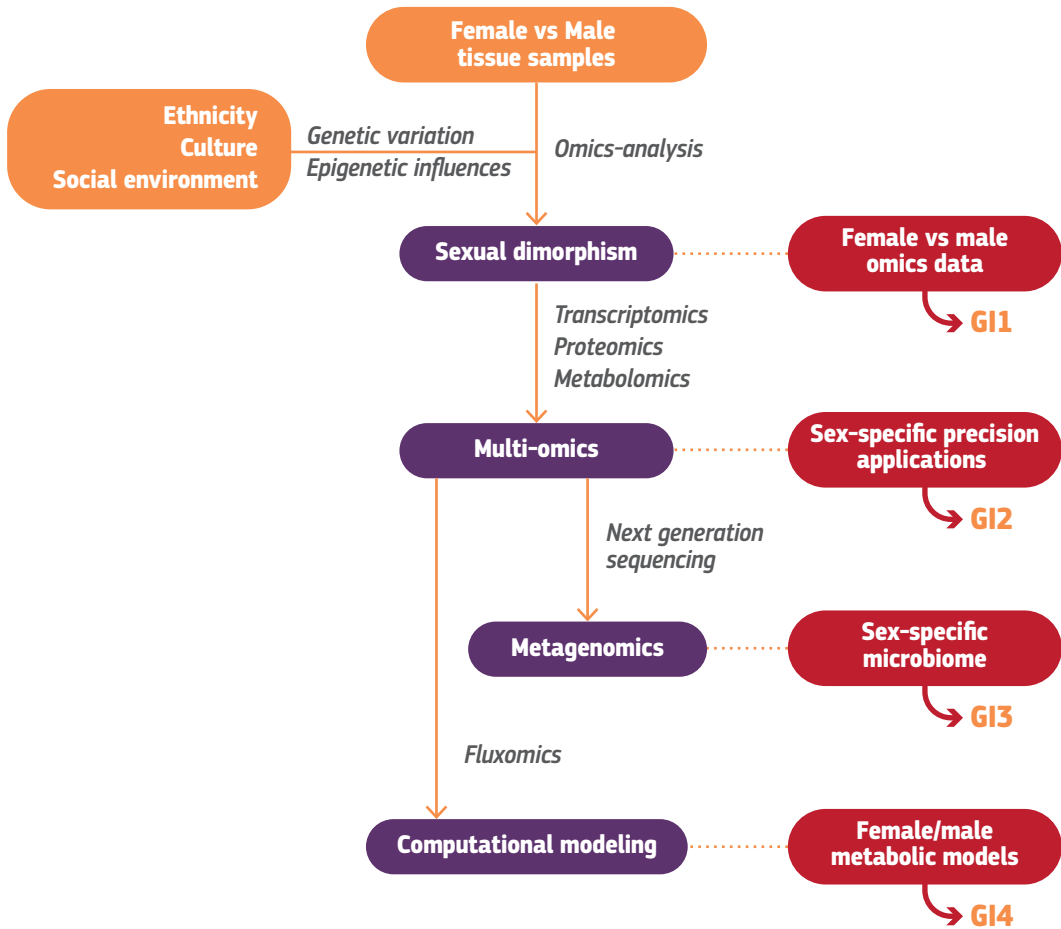
Gendered innovation 1:
Collecting data on sexual dimorphism in gene expression improves biological modelling

Omics studies of animal organs and body fluids have demonstrated sex differences in biochemistry and the regulation of gene activities. In the liver, for example, over 1 000 genes are expressed differently in females and males. Sex differences in metabolic and gene regulatory pathways have also been demonstrated in humans. For example, metabolomic analysis of serum from participants in the German Kooperative Gesundheitsforschung in der Region Augsburg (Cooperative health research in the Augsburg region, KORA) cohort[9] showed significant sex differences in concentration for 102 of 131 examined metabolites (Mittelstrass et al., 2011). Sex-specific genome-wide association studies showed that some of these sex differences resulted from genetic differences. Despite these suggestive results, most systems biology studies have not considered sex.

Data on human sexual dimorphism are limited. Because biopsy material cannot be taken from many of the organs of living individuals, new strategies need to be designed to intensify studies on sexual dimorphism in genome expression such as the use of induced pluripotent stem cells or organoids. Ideally, such studies would take into account differences in lifestyle, ethnicity, and cultural and social background in an attempt to incorporate intersectional factors into the datasets.

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[9] KORA studies are conducted at regular intervals in order to assess the health status of the population in Augsburg and the surrounding area (https://www.helmholtz-muenchen.de/en/kora/).

Schematic overview of the gendered innovations in relation to genetics and genomics approaches underlying systems biology.
© Edwin Mariman

Gendered innovation 2:
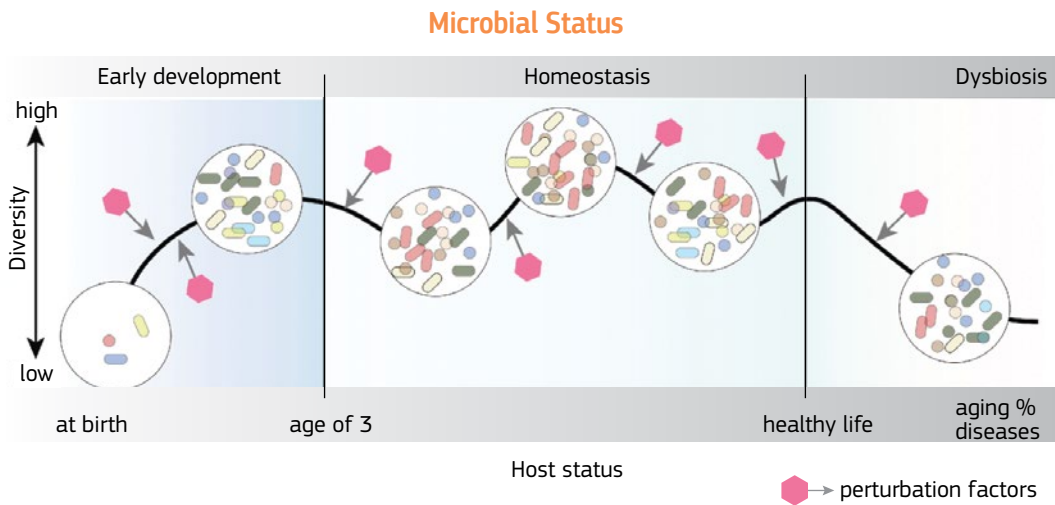## Collecting sex and gender data fuels integrative omics

Integrative omics serves as a foundation for precision medicine, pharmacotherapy and nutrition (Karczewski & Snyder, 2018). Meta-analysis of omics data is a way to find novel diagnostic biomarkers, drug targets or nutritional pathways to prevent the onset of disease. Integrating sex and gender identity into the source data for integrative omics will be an essential first step towards more personalised medicine. Current datasets underrepresent females and lack information about participants' gender identity. Concerning information on the influence of gender identity, in 2018 the gender dysphoria treatment in Sweden (GETS) study was announced to investigate if and how cross-sex hormone treatment to align gender identity with physical appearance leads to metabolic and functional changes including at the genomic and epigenomic levels (Wiik et al., 2018). Big data that include social and cultural information can open the way to sex- and gender-specific precision medicine.

Method: collecting sex- and gender-specific data

The amount, quality and precision of data have an essential influence on research output. The growing use of large datasets and their integration into fields such as precision medicine, pharmacotherapy and nutrition bring this aspect to the forefront. When collecting information about sex, clear decisions need to be made on how sex is operationalised (e.g. through genomics data alone or in combination with hormonal profiles and phenotype). The same applies to the potential inclusion of gender in these analyses. Currently, the only immediately available option is the collection of data about gender identity; however, as instruments become more refined, information on gender norms and behaviours could also be collected. The integration of this information could generate new personalised therapies or preventative offers.

Microbial Status

Development and dynamic changes of the gut microbiome over the course of human life. Perturbing factors help to shape the microbiome during early life but also influence its composition and diversity during adulthood. Some factors may eventually lead to dysbiosis and reduced diversity leading to increased risk of certain diseases.
Source: Chen et al. (2018), with permission

Gendered innovation 3:
Analysing sex improves understanding of the role of the microbiome in health and disease

Awareness of the gut microbiome's role in health and disease is growing. Using gene sequencing to construct a metagenome, researchers can now analyse the composition of the microbiome and quantify different types of microorganisms present in our gut. The microbiome is influenced by the genetic make-up of the host as well as by cultural and societal circumstances. Such sequencing has found differences in women's and men's microbiomes. Sex differences in the microbiome may not only contribute to sex differences of gut-related diseases, but could also underlie sex differences in neurological and neurodegenerative disorders (Thion et al., 2018) (see the Horizon 2020 project A systems medicine approach to chronic
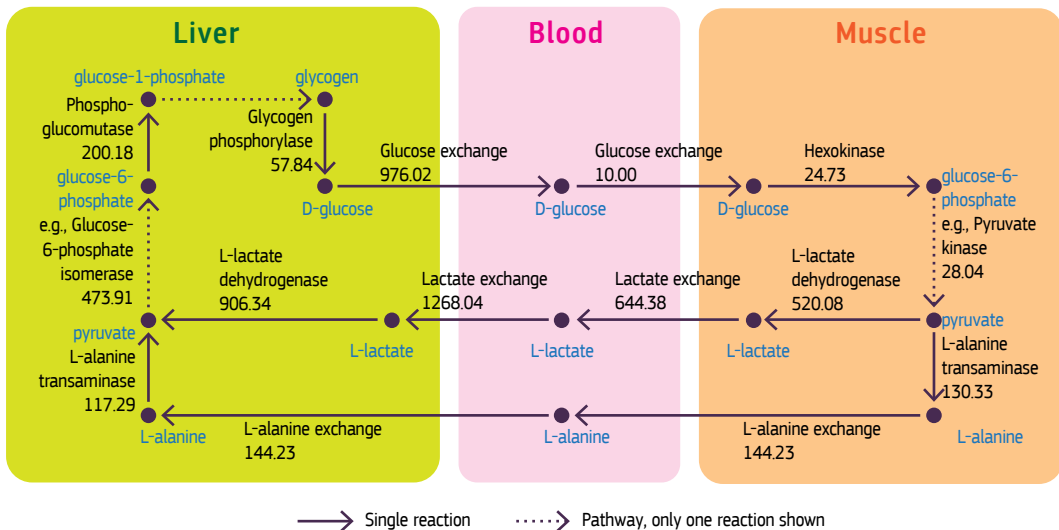
inflammatory diseases (Syscid; Syscid, 2020)). Research has shown that women tend to have microbiomes with significantly higher microbial diversity than men (Chen et al., 2018). The make-up of the microbiome is likely influenced by contraceptives with oestrogen, which modify the growth conditions in the gut. Women's microbiomes display higher resistance to various classes of antibiotics, which seem to follow differences in antibiotics use (Sinha et al., 2019) (see the Horizon 2020 project The role of the virome in shaping the gut ecosystem during the first year of life (BabyVir; BabyVir, 2017)). These novel observations warrant more profound investigation and may result in sex-specific analysis of health and disease.

Gendered innovation 4:
Integrating sex difference into systems biology models

Because biomedical experiments more often use male animals and humans, more data about males than females are available to systems biology researchers. Consequently, mathematical models in biology are almost exclusively based on male data. In order to close this sex gap, journals and granting agencies should promote data collection on females, which is a prerequisite for the generation of female-based models in parallel to the existing male-based models. In the meantime, systems biologists should label the sex of the data on which their models are built.

Naik et al. (2014) constructed the *in silico* model SteatoNet using liver metabolic data, to help research better understand liver disease aetiology, but this model is valid for males only (Naik et al., 2014). Cvitanovic Tomas et al. (2018) have adapted SteatoNet to include sex differences by using data on oestrogen and androgen receptor responses and consequent differences in growth hormone release. They call their computational model LiverSex and hope it will provide insight into sex-dependent liver pathologies. It has been validated for mice, but not yet for humans.

Systems biologic analysis of the metabolic Cori and Cahill cycle fluxes in Harvetta.
Source: Thiele et al., 2018, with permission

In the context of physiology and metabolism, researchers at the universities of Luxembourg and Leiden recently presented two validated, sex-specific, whole-body metabolic reconstructions, named Harvey and Harvetta (Thiele et al., 2018). The models represent the metabolism of 20 organs, 6 sex organs, 6 types of blood cells, the systemic blood circulation, the blood–brain barrier and the gastrointestinal lumen with microbiome. Eventually, such models can be used to determine treatment methods in situations in which experimental testing is impossible, such as for pregnant women.

Conclusion

The human metabolism is influenced by sex and gender where genetic backgrounds interact with environmental factors that include lifestyle, ethnicity, culture and social norms. Systems biology is a relatively new discipline with a growing impact on medical science. In the near future, it will enable the construction of mathematical models that can predict individual risk for common non-communicable diseases and guide best practices for prevention or therapy. Modelling is largely based on omics data, which at present lack information regarding sex and gender. This should be addressed in the following ways:

▸ Studies on sexual dimorphism need to be performed in humans in different living conditions.

▸ Integrative omics will enable more individualised approaches to disease prevention and therapy. Source data need to include information on sex and gender (including cis- and non-binary genders).

▸ The gut microbiome plays a role in health and risk of disease. Since the microbiome differs by sex, analysis of the microbiome should include sex as a robust variable.

▸ Although a few examples of male and female models of the human metabolism have been developed, the majority of published models have been generated using male data. In such cases, the

limitations of the model should be addressed. In some instances, the model can be retrofitted to include sex.

>> **Next Steps**

In systems biology the influence of sex and gender has received only limited attention. However, systems biology is still a young field. It is now the time to incorporate sex and gender as significant parameters in the design of omics experiments and mathematical modelling. Researchers, journals and funding agencies can raise awareness of the limits of single-sex datasets and make sex and gender analysis the norm in genomics, genetics and systems biology research.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

In the context of omics applications and systems biology, it is necessary to integrate sex and/or gender analysis in the following.

Cluster 1: Health

Staying healthy in a rapidly changing society

Research needs to better understand human health during all stages of life, delineating the factors affecting health and defining resilience to disease. Sex and gender are such factors and must be integrated into research design.

Research aims to personalise advice regarding health promotion and disease prevention for individuals, or to tailor stratified solutions for

specific groups. Health and disease are strongly sex and gender related. Personalised and tailored solutions and advice can only be achieved when sex and gender are analysed in the research.

Tackling diseases and reducing disease burden

Research seeks to improve methodologies and diagnostics that allow timely and accurate diagnosis, identification of personalised treatment options and assessment of health outcomes. Methodologies and diagnostics often still exclude sex and gender; incorporating sex and gender analysis (along with other intersecting health factors) in novel research will lead to significant improvement.

Unlocking the full potential of new tools, technologies and digital solutions for a healthy society

Researchers are developing novel tools and technologies for biomedical research, prevention, diagnosis and therapy of diseases, and tools for monitoring treatment progression. Novel tools and technologies will probably be data driven. It is crucial that these source data be clearly and precisely annotated for sex and gender.

Research aims to develop computer models and simulations for understanding health, and improving healthcare and person-centred care. Computer models and simulations must rigorously incorporate sex and gender. Again, this requires that sex and gender be integrated into the production process starting from precisely annotated sex- and gender-specified source data.

Mission area: cancer

Top experts propose that, by 2030, more than 3 million more lives can be saved, with people living longer and better. We can achieve a thorough understanding of cancer, improve prevention, improve diagnosis and treatment, support the quality of life of all people exposed to cancer and ensure equitable access to the above across Europe. Sex and gender are inherent to cancer risk, cancer development and precision treatment. To ensure equitable access for all Europeans, sex and gender must be considered in cancer studies, cancer data analysis and modelling of treatments.

Partnerships on health: personalised medicine

Personalised medicine is a medical model using the characterisation of individuals' phenotypes and genotypes (e.g. molecular profiling, medical imaging, lifestyle data) to tailor the right therapeutic strategy for the right person at the right time, and/or to determine predisposition to disease and/or to deliver timely and targeted prevention. Because sex and gender are elements of each individual's genotype and phenotype, it is strongly recommended that sex and gender be integrated into all research aimed at implementing and improving personalised medicine.

The partnership on personalised medicine will be composed of European and international stakeholders such as health and research/innovation ministries, regional authorities, research-funding agencies and healthcare institutions. Partners are strongly encouraged to incorporate sex and gender expertise into proposals for collaborative and coordinative activities regarding personalised medicine.

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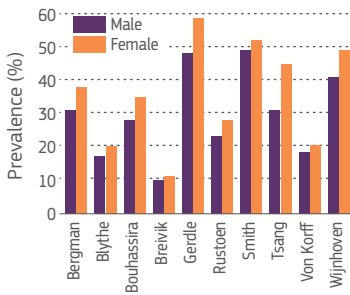# CHRONIC PAIN: ANALYSING HOW SEX AND GENDER INTERACT

© Rosemary Rogers

The challenge

Sex and gender affect all parts of the pain pathway, from signalling, through perception, to expression and treatment. Recent studies have shown that women generally display a lower pain threshold for all types of pain: pressure, heat, cold, chemical or electrical stimulation, and ischaemia (Bartley & Fillingim, 2013; Mogil, 2012; Mogil, 2020). Some researchers attribute these differences solely to biological (sex) differences; others suggest that these observed differences are, at least in part, diminished or amplified by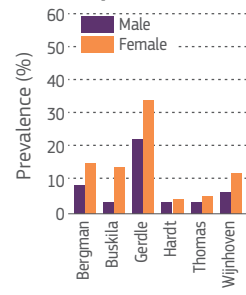 gender (Boerner et al., 2018). The fact that women and men are raised to express pain differently may modify both their biological response to pain and their willingness to report it (Samulowitz et al., 2018). This case study focuses on how sex and gender interact in pain.

Chronic pain affects 20 % of the adult population. 'Chronic pain' means pain that persists past normal healing time and is commonly defined as pain that lasts more than 3 months (Merskey & Bogduk, 1994). Women, men and gender-diverse people all experience chronic pain. A higher prevalence of chronic pain has been reported in women than in men (Greenspan et al., 2007; Mogil, 2012); see figure below. Differences in the sources of pain also vary: migraine, rheumatoid arthritis and fibromyalgia are more prevalent in women, while cluster headaches are more prevalent in men (Sorge & Totsch, 2017).
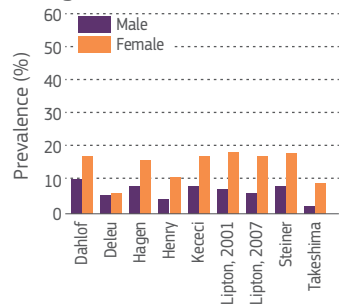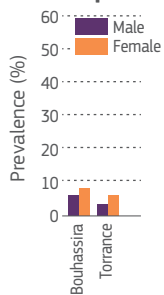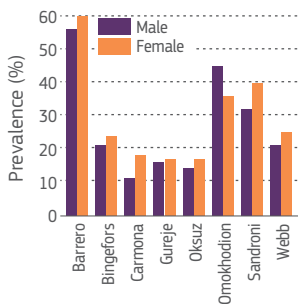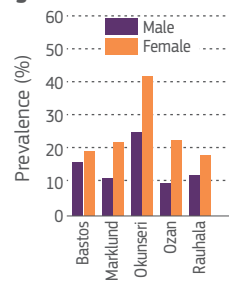

Difference in prevalence of several common chronic pain conditions in females and males.
Data from Mogil (2012); chart created by Jeff Mogil, used with permission

The differences between female-typical bodies and male-typical bodies have been studied the most. Evidence is only beginning to emerge for other genders. Recent reports indicate that transgender people are more likely to suffer from chronic pain than cisgender people (Dragon et al., 2017), but comprehensive statistics in this field are still missing.

Gendered innovation 1:
Studying the underlying biological mechanisms of pain in female-typical bodies and male-typical bodies may promote sex-specific treatment

The nervous system and the immune system are both involved in the development, maintenance and control of chronic pain. In experiments with male and female mice, injuries to peripheral nerves caused increased sensitivity to pain. In females, T-lymphocytes (white blood cells) mediated the response. In males, the response depended on central nervous system cells called microglia (which act as immune cells) instead. The researchers found that testosterone activates microglia and suppresses T-cells, whereas oestrogens activate T-cells. Although in both cases the result is increased sensitivity to pain, the pathways are different. In the future this could possibly lead to the development of female- and male-specific painkillers (Sorge and Totsch, 2017). The researchers were also able to show that changing hormonal profiles throughout the lifespan influenced the pain pathway. Pregnant female mice, for example, switched to the male-typical pathway, while male mice that lacked testosterone switched to the female-typical pathway. If the results can be confirmed in humans, this could have an impact on humans throughout their lifetimes, and affect treatment choices in patients undergoing hormone therapy.

Additional mechanisms might influence pain perception in females and males. Animal studies have shown that the number of certain pain receptors is higher in female brains (Sorge & Totsch, 2017), while the descending pain control pathways – where the brain inhibits pain perception despite injury – activate more strongly in males (Sorge & Totsch, 2017).

Similar sex differences may influence human pain. In the EU-funded Horizon 2020 project Modelling neuron–glia networks into a drug discovery platform for pain efficacious treatments (NGN-PET; NGN-PET, 2019), researchers are modelling neuron–glia networks in an effort to discover new pain treatments. The role of both neurons and glial cells in chronic pain is well documented but has not been exploited to develop novel specific painkillers that target neuronal–glial interactions. One objective of this project is to understand the specific mechanisms involved in common neuropathic diseases and if these explain the higher susceptibility of women to neuropathic pain. This approach might lead to a better understanding of sex-specific pain mechanisms, help identify new targets for pain treatments and improve pain treatments in a sex-specific manner.

Gendered innovation 2:
Studying how sex and gender interact, and how sex and sex interact

Sex and gender interact

Pain perception and expression are influenced by many factors, for example social support, previous experience of pain, ethnicity and the concomitant presence of other diseases such as depression. Gender stereotypes can also modulate pain perception. In a study of 120 men in Germany, two groups of men were enrolled and given opposite preliminary information. One group was told that men were less sensitive to pain than women because of their evolutionary role as hunters, while the other group was told that women are less sensitive to pain because of the painful process of childbirth. The men in the first group reported less sensitivity to pain in the subsequent experiments. The associated functional magnetic resonance imaging study suggests that this gender priming changed pain perception, and not just the willingness to report pain (Schwarz et al., 2019). More research in this area, including with gender-diverse people, is needed.
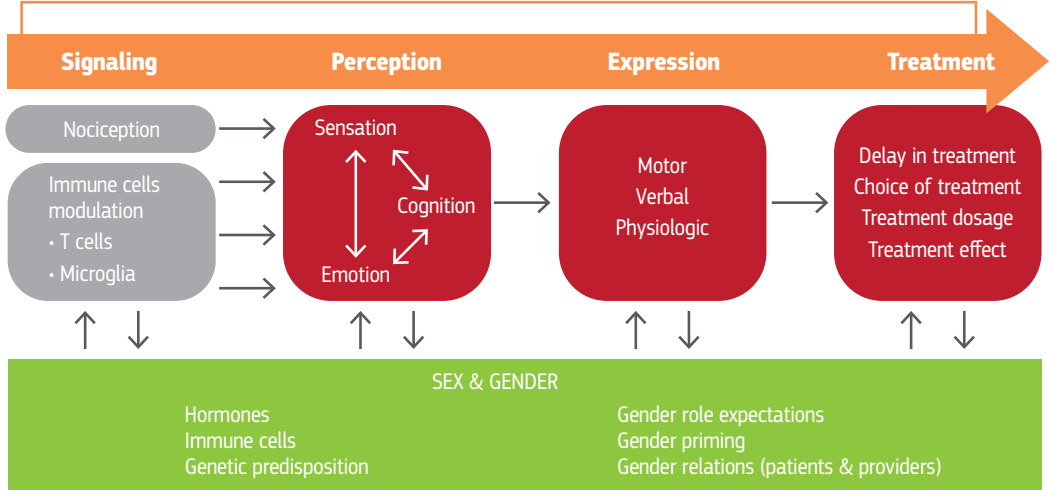
Sex and sex interact

Researchers' sex can also influence response to pain. In animal studies, mice and rats exposed to painful stimuli displayed less discomfort when the experimenter was male than when it was a female (Sorge et al., 2014). The phenomenon appears to be mediated by olfactory stimuli, i.e. the animals smell the pheromones of the experimenter. Male rodents experienced physiological stress when smelling other males (in this case humans), which dampened the intensity of the perceived pain. This phenomenon, which the authors label the 'male observer effect', seemed to be present in both male and female rodents, although it was more pronounced in female rodents.

The role of olfactory substances in the modulation of pain has also been reported in humans (Villemure & Bushnell, 2007). In one study, olfactory exposure to androstadienone (a male sexual steroid) improved mood in women but not in men. When women were exposed to a pain stimulus, androstadienone increased pain intensity among women which might be explained by a heightened attentional state produced by the exposure to steroid hormones. Unfortunately, the researchers did not report the gender identity or sexual orientation of the participants, which might affect the female and male reactions to androstadienone.

Method: analysing how sex and gender interact

How the Interaction of Sex and Gender Influences Pain

Signaling	Perception	Expression	Treatment

Nociception → Sensation

Immune cells modulation
• T cells
• Microglia

Sensation ↕ Cognition ↕ Emotion → Motor Verbal Physiologic → Delay in treatment / Choice of treatment / Treatment dosage / Treatment effect

SEX & GENDER

Hormones
Immune cells
Genetic predisposition

Gender role expectations
Gender priming
Gender relations (patients & providers)

Systems biologic analysis of the metabolic Cori and Cahill cycle fluxes in Harvetta.
Source: Thiele et al., 2018, with permission

Several biological mechanisms influence the signalling, perception, expression and treatment of pain in female-typical and male-typical bodies (Bartley & Fillingim, 2013; Fillingim et al., 2009). Gender roles and stereotypes can also influence pain signalling and perception, although more work is needed to understand these mechanisms. Gender also affects the expression and treatment of pain.

The EU-funded Horizon 2020 project Understanding risk factors and determinants for neuropathic pain (DOLORisk; DOLORisk, 2020) is exploring factors and determinants for neuropathic pain: pain caused by damage to the nervous system. The researchers consider genetic, environmental/societal and clinical risk factors for neuropathic pain. By including gender and sex dimensions in both the genetic and environmental aspects of pain, the authors are increasing the chances of identifying vulnerable patients.

Gendered innovation 3:
How gender affects the reporting and treatment of pain

Gender roles and identity influence how pain is experienced, patients' readiness to report pain and pain management by healthcare professionals.

Patient gender

Men may be less willing to report pain than women because dominant masculine gender roles associate male identity with toughness and stoicism (Robinson et al., 2001; Myers et al., 2003). Similarly, women are expected to report pain more readily. From childhood, girls and boys are frequently socialised to respond differently to pain, and these attributes can vary between cultures and countries (Samulowitz et al., 2018). Researchers have demonstrated that these gender norms can be changed and that this can affect perceived sensitivity to pain (Robinson et al., 2003).

Gender assumptions in healthcare providers

Healthcare providers, who themselves embody gender identity, roles and relations, may treat their patients differently depending on their beliefs and subconscious assumptions. For example, some reports have shown that healthcare providers are more likely to classify pain as of psychological rather than physical origin in women than in men (Hoffmann & Tarzian, 2001). Men who suffer from chronic pain might find their masculinity questioned (Bernardes & Lima, 2010).

Pain might also be managed differently in women and men. Gender stereotypes may influence the treatments that physicians prescribe for women versus men reporting pain, and the choice of therapy in acute versus chronic settings. For example, in emergency medicine and prehospital settings, women with acute pain have been reported to obtain fewer painkillers, especially opioids (Lord et al., 2009), and wait longer than men for treatment (Chen et al., 2008). In these acute settings, women appear to receive more non-specific diagnoses, be treated less aggressively and be prescribed more antidepressants than painkillers compared with men (Hamberg et al., 2002; Hirsh et al., 2013; Hirsh et al., 2014). Conversely, women with chronic pain are more likely to be prescribed opioids than men (Serdarevic et al., 2017; Simoni-Wastila, 2000). This places women at higher risk of developing dependency and overdosing on prescribed opioids than men (Green et al., 2009; Unick et al., 2013). Nevertheless, deadly overdoses are higher in men than in women (Calcaterra et al., 2013). This is in line with the fact that although women attempt suicide more than men, men more often die given their weapons of choice.

Women's higher risk of opioid dependency may be due to differences in metabolism (sex) but also to experiences of trauma or distress (gender), which are more prevalent in women. Some women – including women who have experienced violence, Aboriginal and Indigenous women (in Canada), non-cisgender women and trans women – have been found to be at higher risk of opioid dependency (Hemsing et al., 2016).

The gender relations between provider and patient are complex. Researchers have found that women physicians were more likely to prescribe analgesics (painkillers) to patients in general and opioids to women patients, whereas men physicians were more likely to prescribe opioids to men patients (Safdar et al., 2009). In contrast, in an experimental study (as opposed to an observational one), Hirsh and colleagues found that women providers prescribed more antidepressants and offered more mental health referrals to women patients than to men (Hirsh et al., 2014). Women providers might

be more inclined to consider psychosocial factors with women patients, which is in line with previous reports of the increased tendency of women physicians to discuss emotions and explore psychosocial factors (Roter et al., 2002). However, although emotional and psychological factors can contribute to chronic pain, women, men and gender-diverse patients alike should have equal access to both medication and mental health treatment.

Other sociocultural factors, including age, ethnicity and sexual orientation, can also influence pain treatments. In US emergency rooms, for example, white people are 25 % more likely to receive medication for acute pain than Hispanic people and 40 % more likely than African American people (Hoffman et al., 2016).

Failing to consider how sex interacts with gender in pain may result in poor patient management and lead to chronic pain and patient decline. Gender-sensitive and possibly sex-specific pharmacological pain management is needed to improve patients' outcomes and quality of life.

Conclusions

Both biological and sociocultural differences between women, men and gender-diverse people influence chronic pain at all stages from signalling to treatment. A better understanding of sex-specific neuronal and immune mechanisms in chronic pain might help researchers develop novel and more effective sex-specific treatments. Gender roles and behaviours influence pain expression by patients and treatment by healthcare providers. A better understanding of the influence of sex and gender on pain may improve the quality of care provided to patients, the control of their pain and their overall quality of life.

>> Next Steps

▸ Preclinical and clinical studies must integrate new findings on sex differences in pain pathways to develop new treatments tailored to patient sex.

▸ More research on the interaction between gender and the biology of pain is needed. These studies should include women, men, and gender-diverse and transgender people.

▸ Understanding how gender roles and behaviours affect pain management needs to be taught to future healthcare providers. All healthcare professionals have a role to play in changing gender roles and behaviours, beginning in early childhood, by raising awareness in parents, families and educators.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Cluster 1: Health

Staying healthy in a rapidly changing society

Health policies and actions for health promotion and disease prevention should be knowledge based, targeted to citizens' needs and designed to reduce health inequalities. The prevention of chronic pain should integrate sex and gender into treatments and propose gender-sensitive approaches to pain management.

Living and working in a health-promoting environment

Policymakers and regulators should be aware of and better informed about environmental, socioeconomic and occupational risk factors as well as health-promoting factors, including the combination of factors, for health and well-being throughout society. Accordingly, knowledge-based policies at EU and global levels should better protect and promote citizens' health and well-being, and reduce health inequalities. Integrating social determinants of health, such as gender and ethnicity, into health-promoting policies can help decrease disparities caused by socioeconomic and occupational risk factors.

Tackling diseases and reducing disease burden

The health burden of diseases in the EU and worldwide should be reduced through effective disease management, including through the development and integration of innovative diagnostic and therapeutic approaches, personalised medicine approaches, and digital and other people-centred solutions for health and care. In particular, patients should be diagnosed early and accurately and receive effective, cost-efficient and affordable treatment, including patients with a rare disease, thanks to the effective translation of research results into new diagnostic tools and therapies. Personalised medicine must include gender-sensitive and sex-sensitive approaches. Gender-sensitive and sex-specific pharmacological pain management is needed to improve patients' outcomes and quality of life.

Ensuring access to innovative, sustainable and high-quality healthcare

Citizens should play a key role in managing their own health and care, informal carers (i.e. unpaid carers) should be fully supported (e.g. by preventing overburdening and economic stress) and specific needs of more vulnerable groups should be recognised and addressed. They will benefit from improved access to healthcare services, including financial risk protection and timely access to high-quality essential healthcare services, including safe, effective and affordable essential medicines and vaccines. Access to healthcare (pain management) for men, women and gender-diverse people means avoiding discrimination and stereotypes (e.g. undertreatment of pain in certain population groups).

Mission area: cancer

Beating cancer means not only saving lives, but also extending life expectancy while maintaining a good quality of life for cancer patients and survivors. Pain is a symptom that may accompany cancers or may be a side effect of certain treatments. A better understanding of the impact of cancers and their treatments in men, women and gender-diverse people, could help improve quality of life, whether from a curative or a palliative perspective. In addition, inequities exist in access to treatment, quality of care and support to cancer patients. These inequities may be gender related and addressing them may improve not only patients' prognosis but also their quality of life.

Partnerships on health

By taking gender-sensitive approaches, partnerships on health can better contribute to finding innovative solutions for societal and health challenges, including in the field of pain. For example, the Innovative Health Initiative, which brings together the pharmaceutical, diagnostic, medical devices, imaging and digital sectors, can prioritise people-centred and gender-sensitive healthcare innovations. Personalised medicine partnerships should account for both biological and sociocultural differences between men, women and gender-diverse people in order to develop truly personalised approaches. This will contribute, for example, to developing more targeted and effective pain treatments.

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Climate change, energy and agriculture

MARINE SCIENCE: ANALYSING SEX

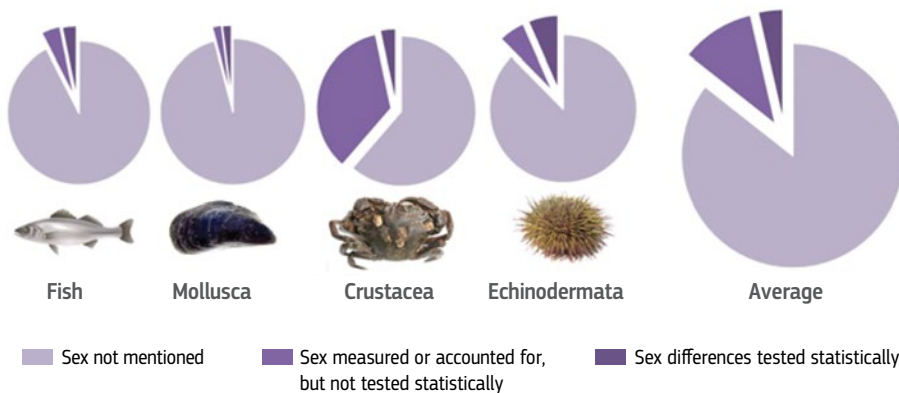*Image by Maica J from Pixabay*

The challenge

Anthropogenically induced climate change is one of the most serious and pervasive global challenges (Hoegh-Guldberg and Bruno, 2010; Diffenbaugh and Field, 2013). To minimise adverse outcomes, it is critical to establish and enforce effective ecosystem management (Hoegh-Guldberg and Bruno, 2010), which in turn depends on a robust understanding of organism and ecosystem resilience to environmental change (O'Leary et al., 2017; Patricio et al., 2019). We do not yet sufficiently understand the extent to which such resilience varies with sex.

The sex ratio of a population is a major determinant of its resilience to environmental disturbance (Ospina-Alvarez and Piferrer, 2008). Sex ratios are driven in part by differential sensitivity of females, males and hermaphrodites to climate change stressors. Nonetheless, sex is rarely analysed as an experimental variable (Tannenbaum et al., 2019). A recent systematic review of ocean acidification literature, for example, revealed that only 3.77 % of recent studies tested for sex-based differences (see figure below), while 85 % of studies failed to consider sex at all (Ellis et al., 2017). This results in a lack of experimental evidence on which to assess sex-specific impacts of ocean acidification, limiting our ability to accurately appraise the resilience of marine populations to reduced seawater pH. Where tested, clear sex-based differences to elevated partial pressure of carbon dioxide (pCO_2) have been documented (Ellis et al., 2017). Failing to account for such differences affects our ability to effectively manage ecosystems and to determine conservation priorities.

Proportion of Ocean Acidification Studies that Analyse sex

From studies on key taxonomic groups (Echinodermata, Crustacea, Mollusca & Fish) published between 2008 and 2016

Fish   Mollusca   Crustacea   Echinodermata   Average

■ Sex not mentioned ■ Sex measured or accounted for, but not tested statistically ■ Sex differences tested statistically

Data Ellis et al., 2017. With permission

Proportion of ocean acidification studies that analyse sex.
Source: Ellis et al. (2017), used with permission

Method: rethinking concepts and theories

A major barrier to the inclusion of sex as an experimental variable is the widely held perception that sex is unimportant for interpreting species' responses to changing environmental conditions. In many instances, such perceptions stem from the lack of documented sex differences in organisms beyond traditional model organisms, such as Caenorhabditis elegans. Challenging such perceptions requires an integrated approach across all three pillars of academic research: policy, publication and education (Tannenbaum et al., 2019). Funding agency policies can drive increased sex-based research in non-model organisms. This increase in research and subsequent peer-reviewed literature will provide the next generation of experimentalists with key examples of how to successfully implement robust methods of sex and gender analysis in relevant areas of research.

A further widely held assumption across both science and society is that sex is binary, genetically determined and fixed at fertilisation. Exceptions to this rule are often considered anomalous (Bachtrog et al., 2014). Throughout nature, however, diverse sexual forms and mechanisms of sex determination challenge these norms and support instead an understanding of a sex continuum (Ainsworth, 2015). Hermaphroditism (the presence of male and female gametes in the same individual), for example, occurs in 94 % of flowering plants (Renner & Ricklefs, 1995) and in one in three species of non-insect animals (Jarne and Auld, 2006). When hermaphroditism is sequential (an individual changes from one distinct sex to another during its lifetime – in some species on more than one occasion), sex is shown to be a labile trait (Munday et al., 2006). Even if distinct female and male sexual forms become clear, unambiguous and fixed, sex determination often depends on an interacting suite of genetic, hormonal, physiological, social and/or environmental processes. In order to understand the importance of sex for basic biology, it is important to consider the mechanisms, timings and direction of sex determination and differentiation, as well as differences in female, male and hermaphroditic responses to environmental perturbation (Ellis et al., 2017; Tannenbaum et al., 2019).

Method: analysing sex

Disaggregating experimental results by sex reveals biologically significant differences that would otherwise be masked if data were pooled (see figure below). To do this, however, requires accu-rate techniques for ascertaining an organism's sex (and where possible these techniques should be non-invasive). The recent development of novel methods for sexing individuals in non-model ma-rine organisms, which include genetic (Benestan et al., 2017; Hines et al., 2007), metabolomic (Ellis et al., 2014; Hines et al., 2007) and endocrine techniques (Jensen et al., 2018), has signifi-cantly enhanced our ability to accurately project climate change impacts in certain groups. But concerted efforts to expand these approaches to wider groups of marine organisms are vital. These efforts will be advanced through the continued innovation and increased affordability of omics approaches.

Impact of Pooling Data for Experimental Interpretation

Data from Cripps et al., 2016 showing impact of elevated pCO_2 on copepod respiration

Biologically important differences between males and females are masked by pooling data

Adapted from Tannenbaum et al., 2019

Pooled experimental data () can mask key biological responses, in this instance the difference in respiration rate of female () and male () copepods under control and high CO2 conditions.
Source: adapted from Tannenbaum et al. (2019); data from Cripps et al. (2016)

Gendered innovation 1:
Understanding feminisation of marine organisms in a warming ocean

Temperature-dependent sex determination (TSD) in marine turtles is perhaps the most widely studied and well-known mechanism of environmental sex determination in nature. However, species that exhibit TSD are also widely considered among the most vulnerable to climate change given the possibility that increasing temperatures favour the production of one sex over the other, destabilising population sex ratios (Mitchell & Janzen, 2010). In marine turtles, sex is determined by temperature during egg incubation, with higher temperatures resulting in a greater proportion of females (Hawkes et al., 2007, 2009; Patricio et al., 2019).

Studies have projected highly female-skewed population sex ratios in marine turtles based on future climate warming, using temperature recordings during incubation as a proxy for population demography (e.g. Hawkes et al., 2007; Fuentes et al., 2011; Laloë et al., 2014). Such

sex ratio estimates, however, depend on the proxy used in sex determination, and may differ substantially when different proxies are used (Fuentes et al., 2011).

Recent advances in the sexing of marine turtles, which combine laparoscopic and endocrinological techniques, have, for the first time, provided empirical evidence for the impact of recent warming on contemporary marine turtle populations. Robust sex analysis enabled the researchers to link male and female green sea turtles to their natal beaches, leading to the discovery that northern (warmer) Great Barrier Reef (GBR) populations have become highly female biased. Over 99 % of juveniles and subadults originating from northern sites are female (compared with 67 % female at southern sites) (Jensen et al., 2018). Despite the ability of marine turtles to maintain population viability even at highly female-biased sex ratios, a subadult female bias of 99.8 % in northern green sea turtle populations indicates that the complete feminisation, and thus local extinction, of northern GBR populations is possible in the near future (Jensen et al., 2018).

Green sea turtle hatchling.
Image credit: 'Green-Turtle_Projeto_Tamar_1' by Oregon State University is licensed under CC BY-SA 2.0 (https://creativecommons.org/licenses/by-sa/2.0/)

Gendered innovation 2:
Understanding environmental sex determination beyond temperature

Sex determination mechanisms fall on a continuum from environmental to genetic. Primary sex differentiation has been shown to respond to a diverse range of environmental factors in a growing number of species. Hypoxia, for example, results in a higher ratio of males in zebra fish (Shang et al., 2006). Ocean acidification, in contrast, results in 16 % more female oysters over a single generational cycle (Parker et al., 2018). Similarly, increased aquatic pH results in more female cichlids (Oldfield, 2005). What is increasingly apparent is that alterations in sex ratio, in either direction, will result in populations less resilient to further disturbance and potentially lead to demographic collapse. A mechanistic understanding of sex-change processes and other ecologically significant sex-based responses is thus vital to accurately model impacts of anthropogenic disturbance (e.g. overfishing or climate change) at a population level.

Gendered innovation 3:
Sex analysis enhances effective population management

An accurate understanding of population structures enhances effective ecosystem management. Recent advances in next-generation sequencing technology has facilitated research focused on the causes and consequences of changes in population structure in a wide range of non-model species (Narum et al., 2013). However, only 9.6 % of studies on marine and diadromous (tolerant of both seawater and freshwater) species have reported sex information (Benestan et al., 2017).

Benestan and colleagues (2017) demonstrate the importance of understanding sex ratios when employing sequencing to interpret population structure. In the American lobster, for example, these authors demonstrate how two subpopulations (inshore and offshore) can be misunderstood as two distinct populations if the sex ratio of samples is unintentionally biased. Studies that sample correctly, i.e. take care to collect equal numbers of males and fe-

males, show that in reality inshore and offshore American lobsters are a connected population that is mixed genetically. Omitting sex information in this instance leads to the incorrect classification of two distinct populations, which in turn may result in ineffective management recommendations.

The American lobster is the most valuable catch in North America. Effective population management has been demonstrated to successfully maximise its sustainable exploitation. Proactive harvester-driven conservation of commercial stocks in the Gulf of Maine, for example, has resulted in record hauls, despite warming (Le Bris et al., 2018). Conversely, in the absence of such management, warming has led to the collapse of the fishery in southern New England (Le Bris et al., 2018).

Accurate population demographic data are especially important when conservation efforts are sex biased. Lobster conservation efforts have protected large berried females (females carrying fertilised eggs on the underside of the abdomen), but not large males. This female-biased protection leads to selective harvesting of large males, which subsequently restricts mate choice and limits sperm, resulting in reduced reproductive success (Tang et al., 2019). In the face of climate change, effective management of this natural resource will become increasingly critical to preserve the reproductive potential of lobster stocks. Robust sex analysis will ensure population structure is understood, and therefore managed and protected accurately.

Gendered innovation 4:
Understanding the differential sensitivity of female and male marine organisms to climate change

Anthropogenically induced climate change results in rising seawater temperatures, ocean acidification, hypoxic zones and storm events. Where tested, sex analysis has emerged as a key parameter for determining species responses to these environmental challenges. Elevated seawater pCO_2 (dissolved carbon di-

oxide), for example, results in differential mortality between the sexes in Crustacea. Both female shrimp (Kurihara et al., 2008) and female copepods (Cripps et al., 2014) show greater sensitivity to climate change than their male counterparts.

This pattern, however, does not always hold, and analyses must be done carefully. In the copepod *Arcatia tonsa*, females show greater tolerance of elevated temperatures (Sasaki et al., 2019). Failing to account for sex differences in response to elevated temperatures risks underestimating population-level impacts by overlooking population decline caused by sperm limitation from greater male sensitivity to temperature.

Sex differences in response to climate change can be complex. A recent study of copepod response to elevated pCO_2 by Cripps and colleagues (2016) demonstrated this complexity. Under normal conditions, males have a higher baseline metabolic rate than females. In response to elevated pCO_2, however, females increase and males decrease their metabolic rate (Cripps et al., 2016). Omitting sex analysis in this case masks sex-specific responses in physiological performance that are fundamental for determining population responses.

The differential sensitivity of female and male organisms to changing environmental conditions can also have a large, indirect and often unexpected impact on experimental outcomes. In marine copepods, for example, environmental conditions influence where individuals aggregate in the water column. Studies have shown that differential energy and reproductive requirements lead females to aggregate primarily in oxygenated surface layers of the water; males cluster in deeper water, where oxygen concentrations are lower, as their location is primarily driven by temperature (Pierson et al., 2017). If this behaviour is overlooked, researchers collecting specimens from a single depth would inadvertently introduce a sex ratio bias that would yield incorrect experimental conclusions.

Conclusions

Incorporating sex analysis throughout marine and environmental science innovation will facilitate discovery, research efficiency, reproducibility and robustness. Recent advances in sexing technologies will enable wider inclusion of sex analysis throughout these disciplines and facilitate better modelling of demographic change among marine organisms. This, in turn, will enhance our ability to effectively manage ecosystems and set conservation priorities.

>> **Next Steps**

To advance sex analysis in marine science and enhance its incorporation throughout the discipline, we recommend the following.

▶ Policy developments in funding agencies and peer-reviewed journals that require sex analysis in marine science, and more broadly throughout the life sciences.

▶ Development of novel sexing techniques for an increasingly wide array of non-model marine organisms, especially for species in which morphological sexual dimorphism is not conspicuous.

▶ Development of sexing techniques to improve accessibility, reliability, cost and ease. The increasing affordability of omics approaches and advances in computing power will enable this.

▶ Development of research that considers the role of hermaphroditism in sex-disaggregated reporting of results (see 'Analysing sex in hermaphroditic species' in Annex B). This will enable better modelling of the timing, direction and duration of sex change, as well as sex determination mechanisms. This research should also consider individual responses to environmental stress where cells/behaviours/physiologies of different sexes coexist simultaneously.

▶ Modelling of ecosystem functioning and responses to climate change that incorporates sex analysis, where sex-disaggregated data of sufficient quality are available. Such an endeavour will improve conservation efforts and designation/management of marine protected areas, as well as enable better management of fisheries.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Cluster 5: Climate, energy and mobility

Advance climate science and solutions for a climate-neutral and resilient society

▶ Produce state-of-the-art science on climate change impacts. Disaggregate results by sex to account for and quantify its role in determining organism response to climate change.

▶ Further study the interactions between climate change and biodiversity. When investigating the impacts of climate change, factors such as sex ratio, sex determination and sex differentiation are key population parameters that determine sensitivity to stress and require further investigation.

▶ Advance climate science and create a knowledge base to inform societal and social transition and to guide the development of policy measures. Sex analysis is an integral component of robust world-class climate change science that must be incorporated into research, education, and environmental management and policy.

Cluster 6: Food, bioeconomy, natural resources, agriculture and environment

Environmental observation

▶ Innovate models and data assimilation to support indicators, scenarios, service capacity and innovation for biodiversity, species and ecosystem health, food security and food safety, marine conservation and natural resource management. Sex as a biological variable must be incorporated as a key component of environmental models that seek to determine species sensitivity to climate change and species interactions. Only such models can be used for evidence-based policy.

Biodiversity and natural capital

▶ Understand and address the drivers of biodiversity loss and their interactions better. Research assessing drivers of biodiversity loss, namely species' sensitivity to stressors and their interaction, needs to assess sex as a factor determining sensitivity.

▶ Effective communication and dissemination activities are critical to raise societal awareness. Sex analysis in the context of climate change provides an intriguing and novel key message highlighting the differential sensitivity of females and males to climate change, the impact of environmental change on sex determination and differentiation, and the role sex plays in population sensitivity. Examples that resonate with the public can inspire action.

Seas, oceans and inland waters

▶ Better understand, forecast and monitor the ocean and its changes, the climate–ocean interface and the impact of stressors and global changes on ecosystems and maritime sectors. Understanding, forecasting and monitoring changes within seas, oceans and inland waters will require the inclusion of sex as a factor determining sensitivity at all levels of experimentation, modelling and mitigation.

Mission area: healthy oceans, seas, coastal and inland waters

▶ Adapt to and mitigate pollution and climate change in the ocean. Sex differences in response to climate change are complex. Incorporating sex analysis is therefore vital to accurately understand the threat of climate change (and other environmental stressors such as pollution) on marine organisms, and thus establish effective and robust mitigation strategies.

▶ Sustainably use and manage ocean resources. Conservation of marine stocks could increase the annual profits of the seafood industry by EUR 49 billion globally (Barbier et al., 2018). Sex analysis is shown to be a key factor for ensuring the effective population management of marine organisms.

Mission area: adaptation to climate change including societal transformation

▶ Inducing adaptation to climate change through societal transformation requires strong, clear and compelling case studies to highlight the challenges facing natural ecosystems, as well as champions to induce change in public perception. Sex analysis in marine organisms provides a key example that can capture the imagination of the general public and inspire public action for change.

Partnerships: food, bioeconomy, natural resources, agriculture and environment

Animal health: fighting infectious diseases

▶ Bring sustainable and innovative solutions to tackle infectious animal diseases. Sex is a key factor determining the susceptibility of animals to disease-causing agents.

Incorporating sex analysis is therefore an important consideration for a partnership on animal health and infectious disease.

Rescuing biodiversity to safeguard life on Earth

▶ Deploy solutions to stop the ongoing mass extinction of species caused by human activity. Key factors determining species extinction in the face of climate change are population stability, sex ratios and the sensitivity of males and females. Sex must therefore be considered in the context of biodiversity loss and safeguarding life on Earth.

A climate-neutral, sustainable and productive blue economy

▶ Sustainably unlock, demonstrate and harvest the full potential of Europe's oceans and seas. Effective population management of marine stocks could result in a EUR 49 billion increase in the annual profits of the seafood industry globally (Barbier et al., 2018). In highlighting the role of sex analysis in effective population management of marine species, consideration of sex is an important consideration for a sustainable and productive blue economy.

Commission priority: the European Green Deal

The European Green Deal outlines key actions to 'boost the efficient use of resources by moving to a clean, circular economy' and 'restore biodiversity and cut pollution', enabling a transition to being the first carbon-neutral continent by 2050 (European Commission, 2019).

▶ **Climate ambition**

- **New EU strategy on adaptation to climate change.** As a key determinant of organism sensitivity to climate change, sex is a critical factor that

must be considered when establishing climate thresholds and strategies for adaptation to climate change.

▶ **Preserving and protecting biodiversity**

- **EU biodiversity strategy for 2030.** The differential sensitivity of males and females to environmental stress, as well as the impact of the environment on sex determination and sex ratio, is a key driver of species extinction in the face of climate change. Any biodiversity strategy must therefore take into consideration the role of sex in determining biodiversity loss or preservation.

- **Measures to address the main drivers of biodiversity loss.** Sex is a significant factor affecting population-level responses to environmental stress, so sex analysis is a critical component of understanding, and subsequently

addressing, the main drivers of biodiversity loss.

▶ **The EU as a global leader**

- **EU to continue to lead the international climate and biodiversity negotiations, further strengthening the international policy framework.** Incorporating sex analysis within international climate and biodiversity negotiations, as well as subsequent policy, will ensure that the EU remains a global leader in this area.

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SMART ENERGY SOLUTIONS: ANALYSING INTERSECTIONALITY

The challenge

Over the past few decades, governments and intergovernmental agencies have set ambitious energy efficiency and reduction targets. For example, the EU's Directive on Energy Efficiency sets a target of 32.5 % increase in energy efficiency by 2030 (Directive 2012/27/EU, amended by Directive (EU) 2018/2002; European Parliament and Council of the European Union, 2012, 2018). These targets are part of the United Nations' global effort to ensure access to affordable, reliable and sustainable energy for all. The UN aims to substantially increase the share of renewable energy in the global energy mix by 2030, which will require expanding infrastructure and upgrading technology (UN, 2015).

Despite energy-efficient construction and smart home installations, energy targets for the EU building sector have not been met. Consumers are often blamed for not using the technologies correctly. At the same time, smart technologies are often complex and frustrating to users. To overcome these problems, engineers and design experts need to integrate user perspectives in the design of technologies for homes and public buildings.

This case study analyses how energy-efficiency projects can integrate gender perspectives, along with sensitivity to age, socioeconomic and other social factors, into design. Getting it right for a broad user base will help realise the potential of smart technologies that support EU and global energy targets.

Gendered innovation 1:
Designing energy-efficient tools that integrate gender perspectives

Over the past few decades, product developers have integrated user-centric perspectives to better meet user needs and expectations. The field of energy efficiency, however, has lagged behind.

Danfoss, an international manufacturer and service provider for energy-efficient smart heating solutions, experienced low sales figures for one of its new products. When looking at its customer base, the company realised that women should constitute 50 % of their users, but they were, in fact, significantly underrepresented. To address the problem, Danfoss teamed up with design-people, a Danish design agency, to investigate the values, motivations and needs of women in relation to technology.

The agency used surveys to cluster users into five segments, characterised by different attitudes to technology.

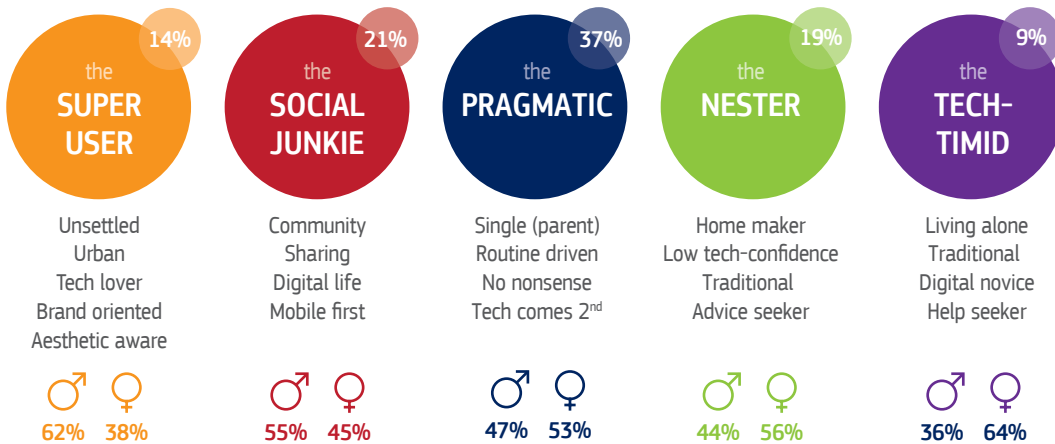The largest segment was characterised as pragmatic tech users (37 %, finely balanced with 53 % women and 47 % men). Danfoss chose this group as the target for the company's new entry-level smart thermostat.

The company created a persona, named Johanna, to represent this group. A careful focus on Johanna's preferences along the entire customer journey allowed the design and engineering team to create an award-winning user experience for the new Danfoss ECO thermostat (https://www.design-people.com/portfolio/danfoss-eco/). Two years after introduction, the sales figures of the new thermostat – a good proxy for user adoption – exceeded Danfoss's expectations.

This approach can be made more inclusive by including other social identities in the survey. The H2020-funded project Energy system transition through stakeholder activation, education and skills development (Entrust; Entrust, 2017) (Dunphy et al., 2017,b) has broadened the design approach to include users of different ages and socioeconomic backgrounds (see below). Other relevant variables may include educational level, race/ethnicity, sexual orientation and non-binary gender identity.

Tech-users Navigator
European Smart Home user profiles (2015)

14%	21%	37%	19%	9%
the **SUPER USER**	the **SOCIAL JUNKIE**	the **PRAGMATIC**	the **NESTER**	the **TECH-TIMID**
Unsettled	Community	Single (parent)	Home maker	Living alone
Urban	Sharing	Routine driven	Low tech-confidence	Traditional
Tech lover	Digital life	No nonsense	Traditional	Digital novice
Brand oriented	Mobile first	Tech comes 2nd	Advice seeker	Help seeker
Aesthetic aware				
♂ 62% ♀ 38%	♂ 55% ♀ 45%	♂ 47% ♀ 53%	♂ 44% ♀ 56%	♂ 36% ♀ 64%

Five customer segments.
Source: design-people (2015), with permission

Danfoss Eco App Thermostat Sales Curve.
Source: Danfoss, with permission

Method: engineering innovation processes

1. Evaluating past innovation practices

By analysing the traditional engineering innovation process of Danfoss smart home appliances, the engineering team identified a lack of diversity in user perspectives as a problem. Without a clear focus on target personas, engineers and designers may subconsciously use themselves as a benchmark for the user experience.

2. Building diverse development and design teams

The Danfoss case clearly demonstrates the advantages of including women and men with diverse attitudes to technology in the design process. Integrating a wide range of new and diverse perspectives will lead to further innovation. New research priorities and research questions can lead to new findings and innovative ideas (see Schiebinger et al., 2011–2020a,b).

3. Analysing users and markets

User needs and behaviours can be identified through surveys, interviews, focus groups and direct observation. Engineers and designers can analyse gender by collecting quantitative survey data, as in the Danfoss example, or by observing user practices and learned behaviours. The best user research will include an intersectional approach to gender, ethnicity, age, socioeconomic status, etc.

4. Obtaining user input

In the Danfoss project, participatory research allowed designers to tap into users' tacit knowledge (see 'Co-creation and participatory research' in Annex B). User research revealed that women valued easy temperature control, air quality control and thermostat design. The engineers had not considered air quality or the aesthetics of thermostat design in the product development, and they had not been confronted with different experiences of the ease of use of their product.

5. Evaluation and planning

To improve the engineering innovation process, companies should assess the benefits and problems of current products and services in view of the users´ expectations and abilities, including all gender types. They should then transfer the lessons learned to other areas of the organisation. Guidelines for the evaluation and planning of the engineering innovation process can be based on design-people (2015) and Schiebinger et al. (2011–2020a).

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Discreet Indoor Climate Sensor.

Based on a 'female interaction concept', Danfoss and design-people translated their research findings and principles into a more user-responsive indoor climate solution, i.e. including not only temperature but also air quality controls. They replaced the wall-mounted control panels with more discreet sensors controlled from tablets and smartphones. This allowed users to balance climate comfort and energy saving by controlling their heating systems remotely.

In addition, Danfoss paid attention to air quality. The surface of the new thermostat and sensors ruptured into crystal patterns when air quality deteriorated, indicating that users should refresh the air.

Gendered innovation 2:
Driving the energy transition by integrating an intersectional approach to gender, age and socioeconomic factors

To tackle the energy transition, the EU-funded Horizon 2020 research project Entrust focused on the social dimensions of the energy system. This project introduced an intersectional approach to understand how gender, age and socioeconomic status affect the transition to a low-carbon energy system. Entrust focused on attitudes to different energy technologies, including energy sources: fossil fuels, renewa-

bles and nuclear energy. Other projects might use different social analytics, such as sexuality, gender-diverse individuals, religion, etc. Each project must hypothesise the social factors most relevant to its goals.

Entrust analysed the daily domestic routines of users from six European communities that differed socially, economically and geographically. The intersectionality approach analysed gender, socioeconomic status and age as these relate to energy practices. The results showed that culture, age or poverty may have more impact on energy use than gender; see also case study 'Climate change'.

Laundry, for example, is a gendered issue. Men often leave laundry to women or to a laundry service, and therefore do not mention it when describing their daily routines (Dunphy et al., 2018a, p. 77). Income also affects laundry practices. One low-income participant (male), conscious of the high cost of electricity, paid extra to buy an ecological washing machine. Two other low-income participants (female) did laundry at off-peak times when electricity rates were lower or simply did less washing to reduce costs. It is important to consider both gender and socioeconomic status as intersecting factors in order to forge solutions that cater for all social groups (Dunphy et al., 20118a, pp. 56–57).

Another example is cooking, which neither women nor men typically mention as energy intensive. In lower-income households, however, both women and, especially, men have developed specific practices to reduce costs when preparing hot meals (Dunphy et al., 20118a, pp. 62–63).

Furthermore, analyses show that older generations consider today's availability of electricity and energy a privilege, not a given. Lifestyle changes that could reduce energy consumption are less appealing to this group (over 65). For different cohorts, different short-term and long-term perceptions of change will affect their choice of energy source and service, as shown below, and intersect with other sociodemographic factors such as gender or socioeconomic status.

	General attitude	Key ideas	Cohort
I	Reluctance to change	Finding it hard to transition, not wanting to give up comforts, shorter term perspective is due to perceptions of shorter life expectancy, energy transition difficult to prioritise in old age. Energy today is often wasted and overused.	65+
		Long-term perception of change.	
II	A problem for the next generation	This is a task for the coming generations. Younger generations are more aware, more educated and have a better upbringing. Younger generations have more years of life to see these changes through. Current quality of life standards are valued high.	45-64; 65+
		Long-term perception of change.	
III	Caring for future generations	Key priority is to achieve sustainability. Ensure wellbeing for future generations. Narratives associated with concerns for young families and welfare of children.	45-64; 25-44
		Short - and long-term perception of change.	
IV	See change now	Critical view of slow pace of change, wanting to see greater efforts toward transition, socio-political factors are a barrier toward change. Greater emphasis on citizenship and reclaiming control over energy issues.	18-24; 25-44
		Short-term perception of change.	

Based on this research, Entrust developed new approaches to public policy, business innovation and community engagement. Twelve business models emerged for energy production and supply, urban environments and shared mobility, with a particular focus on public–private partnerships and community-based approaches. Other approaches included public–private modularised building, community-based energy service companies, peer-to-peer community energy trading, and free-floating car sharing with an operational area (Dunphy et al., 2018c).

Method: intersectional analysis of the energy sector

The Entrust project applies the concept of intersectionality to highlight how various sociodemographic factors interact. The project seeks to understand how energy attitudes and behaviour are shaped by social attributes, such as gender, age and socioeconomic status. The researchers were particularly interested in understanding the life experiences of citizens engaging with the complex sociotechnical networks that constitute the energy system. This intersectional approach allows a more differentiated analysis of energy-related attitudes and behaviours. The following table demonstrates the benefits of an intersectional analysis in comparison with other, more restricted, approaches (Hancock, 2013).

	Unitary Approach	Multiple Approach	Intersectional Approach
Number of Relevant Categories/Processes	One	More than one	More than one
Posited Relationship Between Categories/Processes	None	Predetermined and conceptually distinguishable relationships	Relationships are open empirical questions to be determined
Conceptualization of Each Category	Static at individual or institutional level	Static at individual or institutional level	Diverse; members often differ in politically significant ways
Case Makeup of Category/ Class	Uniform	Uniform	Diverse; members often differ in politically significant ways
Approach to Intersectionality	Lip service or dismissal	Intersectionality as testable explanation	Intersectionality as paradigm/research design

Conclusions

The case study provides clear examples of how to improve R & I processes relevant to energy efficiency measures. It also shows how to improve new and existing technologies and enhance their market acceptance by integrating gender and diversity perspectives into development, design and testing.

>> **Next Steps**

▸ To reach the United Nations SDGs for energy infrastructure and technology, it will be important to implement gender and intersectional analyses as a cross-cutting issue. This will enhance the acceptance and usability of energy products and services, and stimulate the market uptake of energy solutions.

▸ We recommend regular and systematic audits to evaluate energy systems and solutions from a gender perspective and an intersectional perspective.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Cluster 5: Climate, energy and mobility

The long-term targeted impact of this cluster covers climate action as well as energy and transport. This case study is focused on the intersectionality of citizens' gender, age and socioeconomic status, and the impact of these factors on energy demand, use and supply; consequently, our recommendations focus on future R & I actions related to energy, with recommendations for the climate and mobility topics at the end.

Cross-sectoral solutions for decarbonisation

Targeted impact: Increased energy and resource efficiency through attractiveness to citizens and reduced energy consumption, and facilitation of the transformation by engaging

and empowering citizens (European Commission, 2019, pp. 90–91).

▶ Related R & I projects must show an understanding of how to use an intersectional approach to identify different use cases for energy demand and use as well as understanding the variety of expectations involved. Misunderstanding expectations may lead to frustration with R & I actions, and new services, tools and methods, whereas the right analysis and focus on those citizens who are highly motivated may lead to rapid change.

▶ This means that proposed research, innovation and development activities need to consider the impacts on various social groups in order to not leave anyone out. This goes beyond considering gender alone. It requires understanding the effects of energy solutions on all users and citizens. As a result, the new technologies and solutions will become inclusive by default.

Energy systems centred on renewables

Targeted impact: New approaches to enable more interaction and optimisation between producers, consumers, and ensuring cost effective and affordable supply of energy to households and advancing decentralised energy storage for domestic applications (European Commission, 2019, p. 93).

▶ When designing participatory models to engage citizens, research must include methods to understand what motivates citizens to participate or invest time and/or money in the proposed measure. This requires extensive socioeconomic analyses of citizens' underlying attitudes and practices that can then guide investment and policy levers and frameworks. Participatory methodologies also include active citizen involvement in R & D, design and testing processes. This means that researchers or engineers in these

disciplines cannot simply think of and decide what would be best for the citizens (or best for the research); they need to show an awareness that 'the citizen' does not exist but there are a variety of personas (embodying differences related to gender, age, socioeconomic status, ethnicity, etc.) that have to be seen in their specific contexts and have to be involved in feedback and pilot phases.

Develop demand-side solutions to decarbonise the energy system

Targeted impact: 'Delivering the technology and socio-economic breakthroughs … bearing in mind user needs' (European Commission, 2019, pp. 96).

▶ R & I related to the EU building stock must take into account that any renovation work success must go hand in hand with the users/citizens. Cultural backgrounds and types of users (families or singles, high or low income, etc.) need to be considered because they influence user acceptance of the new facilities. Thus, a clear action plan and involvement of relevant users' experience and backgrounds in the project are mandatory.

Mission areas: Adaptation to climate change: accelerating the transition to a climate-prepared and resilient Europe

The mission is built on the active inclusion of citizens, principles of solidarity and intergenerational justice, and a system approach. The mission can only reach its goals if new norms, practices and habits are built, to achieve a systemic change of the socioecological system.

▶ Motivations for change differ strongly among people, depending on their socioeconomic status and way of life as well as their gender, age, and educational and cultural background. The case study on energy provides valuable insights for considering these factors.

▶ The EU Entrust project demonstrates how an intersectional approach reveals motivations for and habits of energy consumptions, e.g. based on the age group of citizens; it also demonstrates that social issues such as income have a significant impact on energy consumption behaviour.

▶ Integrating a gender perspective into innovation engineering processes when designing energy-efficient tools is another example of innovation. It reveals how tools, and especially the design and functionality of tools (e.g. for heating or air conditioning), can be adapted to better fit citizens' expectations and motivations, whether they are at home or at work. Clean air, for example, is very important for parents and for those caring for elderly people. Tools that are easy to understand and operate and also linked to digital monitors of related energy consumption or energy savings can motivate behavioural changes.

Climate-neutral and smart cities, by and for the citizens

Climate city contracts, which also embrace neighbourhoods and their citizens, are a key issue in this mission.

▶ The EU Entrust project shows that human behaviour is not easily changed, and that different citizen groups have different motivations as well as understandings of what makes a valued and safe lifestyle. The intersectional approach is here an equivalent method to take gender into consideration as well as age, education and culture.

▶ To achieve the necessary systemic transition of society, the mission has to identify the group(s) of people whose motivation and lifestyle match the global sustainability goals most closely. Those

groups can implement new habits faster, because their motivation is already strong. This means that the intersectional approach helps to create a faster and thus bigger impact.

▶ On the other hand, all other societal gender and intersectional groups have to be helped to understand the personal transition they need to enable the lifestyle they want. The case study gives the relevant example for the energy sector, which is a key issue for climate-neutral and smart cities.

Partnerships

Built environment and construction

The vision of the partnerships is high-quality, low-carbon, energy- and resource-efficient built environments that drive the transition towards sustainability, including scientific (holistic innovation), economic (sustainable operation) and societal (behavioural change) objectives, and reached through a user-centric approach.

▶ To create a people-centric, sustainable built environment, partnerships need to be strengthened along the value chain all the way to the user/citizen (e.g. by implementing co-development and co-creation activities with the building industry and residents) and across sectors (e.g. construction and transport). Since the impacts of clean energy solutions can differ widely between socioeconomic groups, intersectional factors as well as behavioural and structural determinants of the varying user groups must be taken into consideration here as well as when crafting new solutions. Strategic partnerships between players along the value chain can create solutions that are more widely accepted and have a greater impact.

Clean energy transition

▶ Partnerships are needed between publicly funded research and innovation programmes, industry, public organisations and especially citizens' organisations to create inclusive solutions. Partnerships must also be at eye level to ensure that all voices and ideas are heard, to take well-informed decisions about which solutions to pursue. Equal access for market players, consumers and local energy communities to solutions needs to be a determining factor to ensure the uptake and acceptance of those solutions. Successful methods for citizen engagement and participation need to be considered when shaping energy and transport investment and transition policies. Both researchers and policymakers must understand what motivates citizens to participate or invest time and/or money in these solutions. Based on the extensive socioeconomic analyses of user and citizen attitudes and practices, such drivers can be identified and used as levers and frameworks for investments and policies.

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AGRICULTURE: EMBEDDING GENDER NORMS IN INNOVATION PROCESSES

Image from www.pikist.com

The challenge

Agricultural innovations tend to affect women and men differently. Most innovations focus on resolving technical problems, such as raising yields, withstanding environmental stress and managing poor soil or seeds. Such innovations often fail to account for how gender norms influence the implementation of technical solutions or how the implementation of technical solutions will influence gender norms. Consequently, innovations may not reach women and may even amplify gender inequality (Quisumbing et al., 2014; Bock and van der Burg, 2017; Lawless et al., 2017; Rola-Rubzen et al., 2020; Sachs et al., forthcoming).

Research shows that gender and other normative social structures often lead to unequal benefits from innovation opportunities. Restrictive gender norms are deeply engrained in institutions such as the family, education and banking. These constrain the agency of women, their access to resources and services, mobility, representation and decision-making capacity, especially for less privileged groups (Cole et al., 2015; Badstue et al., 2018). This is the case worldwide (Bock and Shortall, 2017), but solutions need to be context specific.

Gender-transformative approaches have been developed to address these issues by:

- fostering the critical examination of gender roles, norms and relations;
- recognising and strengthening positive norms that support equality;
- promoting the position of women, girls and marginalised groups;
- transforming underlying social structures, policies and broadly held beliefs that perpetuate gender inequality (Petesch et al., 2017, 2018a–c; Badstue et al. 2018; Danielsen et al., 2019; see also Hillenbrand et al., 2015; Aregu et al., 2019; van der Burg, 2019; Fischer et al., 2019).

> **Agricultural science** covers research on crops, livestock, fishing, forestry, horticulture, trees, soil, natural resources, food, biofuels and related production processes, as well as their management, such as natural resource management covering water, post-harvest processing, supply and added value chains, markets and consumption (Meinzen-Dick et al., 2010).

Gendered innovation 1:
Gill nets in Bangladesh

To overcome food poverty, WorldFish led the United States Agency for International Development (USAID)-funded project Aquaculture for income and nutrition, with local partners in Bangladesh (Keus et al., 2017). WorldFish is one of the institutes of the worldwide CGIAR. The project combined the introduction of new technology with a gender-transformative approach (Kruijssen et al., 2016; see also World-Fish, 2016a,b)

Fish is the most important animal-source food in Bangladesh. Approximately 60 % of the population eats fish at least every other day, with daily per capita consumption at 44 grams for the poorest households. In 2012, around 4.27 million households (20 % of rural households) had a fish pond (Belton and Azad, 2012).

we can harvest fish standing on the land with the net.

Gender-related cultural and religious expectations prohibit women from harvesting fish even from their own ponds. Such tasks are seen as the responsibility of men. Women are also reluctant to enter ponds because they get their sarees wet, which then need to be laundered. As a consequence, women mostly feed the fish and help clean the ponds, while men harvest and market the fish, and make financial decisions for the household.

To support gender equality and to ensure food security, WorldFish started to introduce mola gill nets in the poorest parts of Bangladesh. Gill nets are fishing nets that are lightweight enough for women to cast from the bank of the pond, without getting into the water.

Gill nets come in meshes of different sizes. Mesh size determines the type of fish caught. A fish swims into the net but passes only partway through the mesh. When it struggles to free itself, the netting slips behind the gill cover to trap the fish. Since the nets are used to catch only nutrient-rich mola fish (*Amblypharyngodon mola*), men did not feel threatened, as there was little danger of netting the larger fish, which men catch and regard as theirs.

Women attended an 8-day training course on how to make and use a gill net. The nets were 7.5 metres wide by 1.8 metres high. Women were taught to make their own nets by buying low-cost mesh and rope from the market and using empty bottles (for floats) and rocks or broken bricks (as sinkers). Harvesting fish with these nets takes around 30 minutes from setting the net to pulling in the catch.

Method: co-creation and participatory research

Project researchers compared five nets with different mesh sizes to identify which nets performed best for catching small fish and which nets best met women's needs and preferences. They found that gill nets with 1.7-cm mesh were women's top choice.

Women were also taught to manage mola fish farming and were provided with nutrition education on mola. Mola is a small fish rich in vitamin A, iron and zinc. When eaten whole, including the head, organs and bones, mola is rich in micronutrients, which are important for good health and child development. The mola gill net allows frequent harvesting and consumption of mola. Just 17 mg of mola can provide the recommended vitamin A intake for a child under the age of 5 (Kataki, 2002).

Method: analysing gender

Crucial to the success of this project was recognising and transforming gender norms. Because fishing has traditionally been men's work, workshops addressed gender consciousness to ensure that husbands, in-laws and neighbours supported the new role of women in cultivating and catching fish with gill nets. These workshops addressed gender dynamics ranging from intra-household power hierarchies to food distribution. They also addressed gender norms that limited individual and family well-being and enhanced ways to collaboratively shift gender relations. These workshops are outlined in the manual *Promoting Gender-Transformative Change with Men and Boys* (Promundo-US and the CGIAR Research Program on Aquatic Agricultural Systems, 2016), discussed under 'Gendered innovation 2' below. Women were also coached in self-confidence, negotiating skills and assertiveness. Results showed changed attitudes among men and women, enhanced collaboration between family members and greater acceptance of technology uptake by women (Kruijssen et al., 2016; IFPRI Gender Breakfast with CARE and WorldFish, 2017; personal information from A. Choudhury, WorldFish, 23 June 2017). WorldFish also monitored changes in production, attitudes and practices (both technical and social) through surveys and interviews with women, their partners and other household members (Kruijssen et al., 2016).

Gendered innovation 2:
Embedding gender norms in innovation processes

Through Gennovate (n.d.), gender experts from CGIAR institutes, including WorldFish, collaborated to integrate social processes and especially gender norms into large-scale agricultural R & D programmes. They developed extensive methodologies, reports, articles, briefs and videos for research teams in this 4-year research project (2014–2018), sponsored by the Bill and Melinda Gates Foundation. Gennovate advanced in-depth research methods to understand how gender norms and innovation processes in agriculture and natural resource management influence each other, in diverse rural settings.

Its core research addressed the following questions (Petesch et al., 2017).

1. How do gender norms advance or impede the adoption of innovative technologies in agriculture and natural resource management across different contexts and social structures?

2. How and where do new agricultural technologies or practices advance or weaken women's agency and change gender norms to the benefit or harm of women?

3. When and under which circumstances do changes in gender norms and women's and men's agency catalyse innovation and promote inclusive outcomes? What contextual factors influence this relationship?

Gennovate exemplifies standardised methodologies and tools for research that include gender norms. Its conclusions are based on the participation of over 7 000 men and women from 137 rural communities in 26 countries in dis-

cussion groups and interviews (split by sex, age and socioeconomic status; see Badstue et al., 2018; Petesch et al., 2018a).
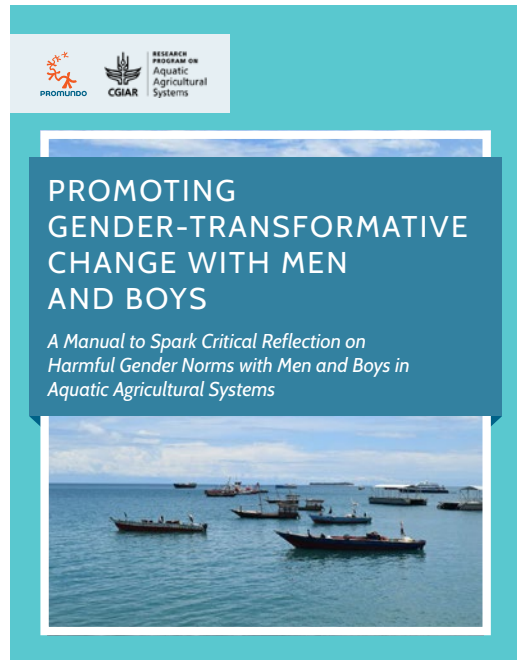
Gennovate's methodologies for examining gender norms can be applied in any gender-sensitive baseline study or preferably in an *ex ante* gender impact assessment (GIA) as part of a large-scale agricultural R & D programme.

The manual *Promoting Gender-Transformative Change with Men and Boys* (Promundo-US and the CGIAR Research Program on Aquatic Agricultural Systems, 2016), developed by Promundo and CGIAR-WorldFish, contains 13 activity-based group sessions to engage men and boys in gender-transformative dialogue as developed for aquatic agricultural systems. The sessions focus on:

▸ understanding how power and gender inequality perpetuates poverty and harms well-being;

▸ taking action to create more inclusive environments for women in aquatic agricultural development;

▸ promoting shared financial and household decision-making;

▸ increasing negotiation and communication skills;

▸ promoting men's involvement in care work; and

▸ understanding how to stop cycles of violence.

Conclusion

Early evidence suggests that gender equality is enhanced when the introduction of a technological innovation is accompanied by a gender-transformative approach. Kruijssen et al. (2016) state that projects are able to trigger transformation in norms when focusing on the root causes of inequality, such as traditional attitudes and behaviour, internal functioning and outreach routines in institutions and gender-specific norms, that limit women's participation.

PROMOTING GENDER-TRANSFORMATIVE CHANGE WITH MEN AND BOYS

A Manual to Spark Critical Reflection on Harmful Gender Norms with Men and Boys in Aquatic Agricultural Systems

An integrated systems approach that starts from the interaction of technological and social dimensions may produce favourable outcomes, as demonstrated in the example of gill net fishing in Bangladesh. It demonstrates how an agrifood or farm systems approach that integrates different participants and activities (diverse crop, livestock and natural resource management) is best equipped to include the gender dimension (Fisher et al., 2019; van der Burg, 2019; Feldstein, 2000). Gennovate provides the research evidence and methodological tools to address the ways in which gender norms influence and are influenced by innovations in agricultural and resource management.

This gender-transformative approach gives new entry points to advance transformative change worldwide – including in European agricultural contexts – that goes beyond women's representation and includes addressing the root causes of existing inequalities. The methodologies developed for in-depth gender analysis and *ex ante* GIA combined with co-creation and participatory research are relevant to EU-funded projects, such as Farming tools for external nutrient inputs and water management (Fatima, http://fatima-h2020.eu; Fatima, 2017) (e.g. Osann, 2018), Social innovation in

marginalised rural areas (SIMRA, http://www.simra-h2020.eu; SIMRA, 2020) (Ravazzoli et al., 2019), Small farms, small food businesses and sustainable food and nutrition security (SALSA, http://www.salsa.uevora.pt/about-salsa/; SALSA, 2020) (Sutherland et al., 2019), New entrant network: business models for innovation, entrepreneurship and resilience in European agriculture (Newbie, http://www.newbie-academy.eu; Newbie, 2020) and more in the future. The EU project Gender in science management of agriculture and life sciences, including research and teaching (Gender-SMART, https://www.gendersmart.eu; Gender-SMART, 2020) is further elaborating how to include gender analysis and address gender and other social norms in agricultural R & D. Gender-SMART is part of the science with and for society programme and funded by Horizon 2020 grant No 824546.

>> Next Steps

The good practices presented in this case study can be broadly applied in agricultural R & D. They can be further supported and expanded in the following ways.

▶ New designs of agricultural R & D projects should include gender and other social norms, especially in baseline studies or ex ante GIAs. Gennovate researchers have already provided examples (e.g. Farnworth et al., 2017, 2018a,b; Kawarazuka et al., 2018; Rietveld and Farnworth 2018a,b; Bergman Lodin et al., 2019; Lawless et al., 2019).

▶ European research on agricultural innovation will benefit from addressing the influence of gender and other social norms on access to and benefits from resources such as land ownership, training, credit, mobility, decision-making power, and support from family and community members (EIGE, 2016; Bock and Shortall, 2017).

▶ Research in this area calls for an intersectional perspective to address heterogeneity in women and men related to other social dimensions or identities, such as socioeconomic status, geographical location, family structures, religion, ethnicity, age and physical ability (see for example Elias et al., 2018; Rietveld et al., 2020; van der Burg, forthcoming).

Policy

▶ Commission comparative research into the design and implementation of innovations that contribute to social and gender equality in agriculture, forestry, fisheries and nature management in various rural settings in Europe and around the world.

▶ Support coordinated awareness-raising about the influence of gender and other social norms in (inter)national agriculture-related organisations and platforms such as European innovation partnerships, and provide them with instruction manuals on how to sustainably reduce inequality and achieve higher equality through innovations.

▶ Request context-specific *ex ante* GIA research as part of research and policymaking.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Since transition is key to the strategic plans for Horizon Europe, an urgent challenge is to achieve transformative change sustainably. Research can significantly sustain the far-reaching transformation in the agricultural and food sector that the European Green Deal demands, especially under the Farm2Fork strategy (European Commission, 2020). Success will depend on the contribution of all rural residents, whether in farming or not, whether permanent or temporary, of all genders, ages, nationalities, cultures, etc. and across all European regions. To secure the active engagement of all and to ensure that transitions will benefit all, gender disparities, and gender and other social norms, should be analysed and addressed from the outset in order to better advance equality and equal benefits in social outcomes and impacts.

To implement transformations that will promote gender and social equality (SDGs 5 and 10), R & I needs to consider the influence of gender and social norms in relation to other SDGs, such as reducing poverty, including rural poverty (SDG 1), eliminating hunger (SDG 2), responsible consumption and production (SDG 12), climate action (SDG 13) and life below water and on land (SDGs 14 and 15).

It is important to include gender norms in baseline studies, to include *ex ante* GIA in research design and to include gender analysis of specific contexts in order to understand the needs and perspectives of all gender-diverse individuals in all agriculture-related domains and rural settings, whether these individuals are directly or indirectly participating or affected.

Cluster 6: Food, bioeconomy, natural resources, agriculture and environment

Circular economy, the bioeconomy, the blue economy, agroecology and the food system in Cluster 6 are all presented as providing opportunities to balance environmental, social and economic goals, and set human activities on a path to sustainability. It is acknowledged that the challenges and impacts in this cluster are highly interconnected, and systems-based approaches will be encouraged. Multi-actor involvement, as well as interdisciplinary or even transdisciplinary approaches in the R & I orientations, is encouraged.

Carefully investigate all social aspects and, in particular, integrate in-depth social and gender analysis and apply *ex ante* GIA to determine who will benefit and who will not from the implementation of sustainability and economic growth. Currently, these key research areas do not analyse by gender and other social factors and do not evaluate gender and social impacts as part of these systems-based approaches.

Consider how the quality of urban and rural lives can be improved while advancing equality, not only at the individual level but also structurally, within sectors, regions and vulnerable environments.

Consider including the gender dimension as it intersects with other social dimensions in ecological, agricultural and food transitions, by operationalising, investigating and assessing gender and other inequalities with regard to:

▸ technologies, digitalisation, new business and governance models, and social and environmental innovation;

▸ growing efficient management and sustainable use of biological resources;

▸ socially disadvantaged regions;

▸ representation and voice in multi-stakeholder living labs;

▸ interactive and integrated approaches to fair and just pathways.

Consider including specifically the rural context and rural inhabitants alongside the focus on the producers and consumers of the agricultural and food sector in general.

Synergies between Cluster 6 and other clusters

Cluster 6 is linked to other clusters because agriculture and food relate to all aspects of society. This means that the gender analysis and gender-sensitive approaches developed in other clusters will benefit Cluster 6; and Cluster 6 can support other clusters by integrating agricultural and rural contexts into their thematic gender analyses. Clusters 1–5 include in-depth analysis of socioeconomic and cultural factors but require better integration of rural and agricultural contexts. All clusters should work together (and not in silos).

Synergies with Cluster 1: Health

Staying healthy in a rapidly changing society

▶ Consider the different ways in which societal changes affect female and male farmers and female and male (including foreign or refugee) seasonal farm workers.

▶ Analyse gender-specific health issues resulting from gender-specific responsibilities for family farms.

▶ Consider how family organisation and composition differ by gender and other social dimensions, such as generation, religion, race, ethnicity, class/wealth, geographical location, civic, marital status and health status.

Living and working in a health-promoting environment

▶ Consider the occupational health risks to farmers and farm workers of all genders related to transition-related stress, high-risk equipment and chemicals.

Ensuring access to innovative, sustainable and high-quality healthcare

▶ Consider rural areas when defining high-quality healthcare systems.

Synergies with Cluster 2: Culture, creativity and inclusive society

Help reverse social, spatial, economic, cultural and political inequalities and their causes, and promote gender equality

Consider how agricultural and rural transitions contribute to the social inclusion of marginalised groups by integrating these groups into researching, planning, implementing, monitoring and evaluating rural and agricultural programmes:

▶ include and address the influence of gender and other social norms;

▶ consider how the effective participation of rural women – and farm women in professional organisations – at local and other levels of governance can be secured;

▶ protect the transfer of tangible and intangible rural and agricultural cultural heritage produced by women, men and gender-diverse individuals, for instance in traditions and rituals, traditional handicrafts, music and dances, but also in food cultivation, wild food gathering, herbal medicines, storage and preservation techniques, and meal preparation;

▶ connect heritage practices, where appropriate, to rural and agricultural transition challenges, health support systems, economic growth and mobility (entrepreneurship in tourism, rural business), and civil security (rural extremism).

Synergies with Cluster 3: Civil security for society

Disaster-resilient societies

▶ Consider that farmers of diverse genders are key in preventing and fighting natural disasters; include gender differences and gender norms in farming people's perspectives on risk management, prevention and actions when researching and preparing new arrangements and measures. Include the intersections of gender with other social dimensions.

Safety of public space, vital infrastructure and societal functions, and fighting crime and terrorism

▶ In rural areas, safety can be an issue, since there is less formal policing. Undermining forces do increasingly take control in rural areas, for instance by illegally producing and trading in drugs. Violence constitutes a particular risk to rural women and gender-diverse individuals, as remote housing prevents effective formal or social control, and specialised social services are absent. Investigate and include these specific risks as well as prevention and resilience options.

▶ Farmers can help prevent natural disasters; it is important to include gender differences in farmers' perspectives on risk management, prevention and actions.

Synergies with Clusters 5 and 6: Climate, energy and mobility and Food, bioeconomy, natural resources, agriculture and environment

Ensure that villages and small towns and their inhabitants are included in climate, energy and mobility missions.

▶ Include rural and gender impact assessments from the very beginning of

the research process in order to identify potential patterns of exclusion and redress them up front.

▶ Include rural areas and their inhabitants in smart innovations to assure the maintenance of infrastructure and its viability. Be sure to assess gender needs, norms and conditions.

▶ In addition to individual users, consider how sectors, such as in agriculture and natural resource management, will be affected. These sectors can be included by adding sectoral gender analysis and impact assessments.

▶ Consider the specific circumstances and addres differences between women and men in access, resources, affordability and connectedness.

▶ Take into account how not only individual users but also sectors, such as agriculture and natural resource management, are affected and can be included by adding sectoral gender analysis and impact assessments to recognise direct and indirect effects on inequalities while decarbonising the EU's economy and working towards a full circular economy.

Mission areas

Accelerating the transition to a climate-prepared and resilient Europe

▶ As stated above, include rural and gender impact assessments from the very beginning of the research process in order to identify potential patterns of exclusion and redress them up front.

▶ Include rural areas and their inhabitants in smart innovations to assure the maintenance of infrastructure and its viability. Be sure to assess gender needs, norms and conditions.

- In addition to individual users, consider how sectors, such as in agriculture and natural resource management, will be affected. These sectors can be included by adding sectoral gender analysis and impact assessments.

- Implement a just transition as mentioned in the Farm2Fork strategy (equity between regions, fair trade or affordable food) by investigating gender and other social dimensions in the content of the R & I. Literature to support this includes Bock and van der Burg (2017), Allwood (2017), Swim et al. (2018) and Alston (2014).

Regenerating our ocean and waters by 2030

In addition to training and upskilling a new gender-balanced blue workforce, this mission uses the wording of 'citizens', 'communities' and 'governance' without operationalising how to address existing inequalities. Internationally, concerns have been expressed that environmental sustainability now overshadows concerns about social equity. It is important to understand that sustainability as fairness and environmental sustainability are two sides of the same coin. Inequality in national ocean economies should therefore be explicitly addressed (see Österblom et al., 2020):

- include gender analysis and *ex ante* GIA to optimise equality in working and living pathways, livelihood, labour force, foodways, new technologies and education.

Caring for soil is caring for life

Gender is mentioned only once in this mission in regard to inclusive language. Sex and/or gender analysis must also be integrated into the R & I content:

- address gender and intersectional transformative approaches in this mission.

Partnerships

Partnership for Accelerating Farming Systems Transition: Agroecology Living Labs and Research Infrastructures

European Partnership for Blue Oceans

Partnership for Animal Health

Partnership for Safe and Sustainable Food Systems for People, Planet and Climate

Partnerships tend to emphasise ecological practices in relation to cost-effective solutions and often overlook the need to foster social equalities. For all partnerships:

- analyse gender and intersectional factors to ensure that environmentally friendly measures will support social equality, including gender equality, and avoid social harms;

- consider gender-sensitive communication strategies and inclusive governance as these intersect with other social dimensions, such as ethnicity and socioeconomic status.

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Urban planning, transport

SMART MOBILITY: CO-CREATION AND PARTICIPATORY RESEARCH

The challenge

Mobility patterns are gendered. Typically, one can observe, for instance, gender norms, gender-specific divisions of labour in households and gender disparities in resources. Gendered household labour is particularly important on the demand side, since trips related to caring – running the household, errands or caring for others – are different from commuting to work in terms of distance and frequency. Another aspect to consider is safety, which is of particular importance to women, who tend to feel more at risk when using public transport than men. On the supply side, urban transportation is increasingly offering smart mobility options underpinned by ICT platforms designed to ease access to transportation services and to personalise modern transportation. These developments, however, have largely ignored gender (Nobis and Lenz, 2009, 2019; Lenz, 2020).

To close the gap between gender-specific needs and new smart mobility services, we need to (1) understand gender-specific needs throughout populations by also taking into account other aspects, such as abilities, age, ethnicity and socioeconomic status, and (2) develop and apply gender-sensitive methodologies to assess those needs and to co-create services that enhance mobility options.

Gendered innovation 1:
Mobility of care

Effective transportation systems rely on big data. Transportation planners collect data to understand how people use different modes of transport: cars, bikes, trains, underground railways and buses. The gendered innovation is to reconceptualise how data are collected and analysed.

Researchers examining public transport often categorise trips by purpose, to better understand existing transportation patterns and to plan infrastructure changes. Traditional categories used in transportation surveys collect information about trips for employment, education, shopping, leisure and the like (see left-hand side of graph below). Categories used by European national household travel surveys, such as the ones in the Netherlands or Germany, for example, include trip to work, work-related trip, trip to kindergarten/school/university, shopping/running errands, activities, picking someone up/dropping someone off, leisure, accompanying an adult person, sports, meeting friends, home,
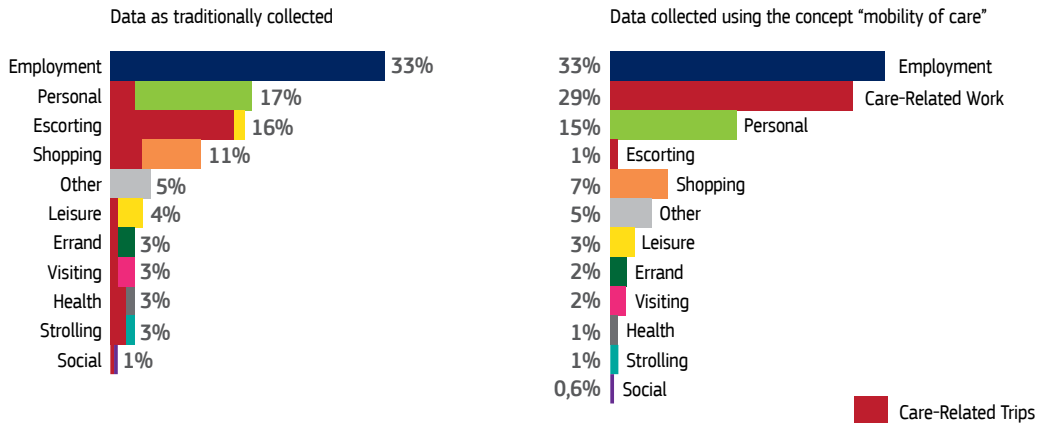
other private activity. This includes the recommendations made by Eurostat (2018).

The innovative concept 'mobility of care' reveals significant travel patterns otherwise concealed in data collection variables (Sánchez de Madariaga, 2009, 2013). The charts below represent public transport trips made in Madrid, Spain, in 2014. The left-hand side of the graph below displays transportation data as traditionally collected and reported. It privileges paid employment by presenting it as a single large category. Caring work (shown in red) is divided into numerous small categories and hidden under other headings, such as escorting, shopping and leisure.

The right-hand side reconceptualises public transport trips by collecting care trips into one category. Visualising care trips in one dedicated category recognises the importance of caring work and allows transportation engineers to design systems that work well for broader segments of the population (Sánchez de Madariaga and and Zucchini, 2019).

Method: reconceptualising data collection

TRIPS BY PURPOSE, POPULATION 30–45 YEARS, MADRID 2014

Data as traditionally collected

Employment	33%
Personal	17%
Escorting	16%
Shopping	11%
Other	5%
Leisure	4%
Errand	3%
Visiting	3%
Health	3%
Strolling	3%
Social	1%

Data collected using the concept "mobility of care"

33%	Employment
29%	Care-Related Work
15%	Personal
1%	Escorting
7%	Shopping
5%	Other
3%	Leisure
2%	Errand
2%	Visiting
1%	Health
1%	Strolling
0,6%	Social

Care-Related Trips

Traditional data collection categories (left) and the new umbrella category mobility of care (right).
Source: Sánchez de Madariaga and Zucchini (2019), with permission

Reconceptualising data collection is important because women perform a relatively large proportion of accompanying trips. They make more short trips and more chained trips (several destinations visited along the same route) than men. Women also tend to prefer shorter distances between home and the workplace. These observations are true in particular of households with two or more adults between the ages of 30 and 50. These differences do not apply to younger or single-person households (Nobis and Lenz, 2005).

Gendered innovation 2:
Analysing gender to enhance fair mobility

Beyond how data are collected and analysed, it is important to develop gender-sensitive methodologies to better address the needs of public transport users.

To introduce dynamic ICT-based public transport services, a 'LivingLab' was set up in Schorndorf (Germany), to experiment with gender-sensitive methodologies (Center for Interdisciplinary Risk and Innovation Studies, 2018; Gebhardt et al., 2019). The objective was to make public transport more user-friendly and more efficient. To this end, conventional public transport was transformed into an on-demand bus service at times when demand tended to be low and variable, such as evenings and weekends. The service used a digital platform with access by a smartphone app, the internet or telephone. The LivingLab introduced smaller buses with flexible routes and a dense pattern of flexible stops that allowed people to get on or off the bus close to the start or end of their journey. Users did not have to walk to traditional designated bus stops.

This gender-sensitive on-demand service addressed the specific needs of women and contributed to the comfort of all users in need of safe and efficient off-peak services.

▸ Users, especially young women and girls, found the on-demand bus provided a safe way home. Longer walks from the flexible

bus stop to home, sometimes leading through pedestrian underpasses, could be eliminated. At the same time, waiting times for the bus were considerably reduced.

▶ Smaller on-demand buses provided an improved feeling of safety for people travelling in the evening or at night, as all seats were close to the driver. (The need for the presence of a driver to ensure safety was a reason women argued against autonomous vehicles.) Providing mobility services that are perceived as safe enhances options for out-of-home activities, especially for elderly people, who often restrict those activities to daylight hours (Giesel and Rahn, 2015).

The LivingLab included participatory research, in which users contributed to concepts and evaluated designs (see method below). Users emphasised a need for multifunctional spaces in the on-demand vehicle that could accommodate pushchairs, shopping trolleys or walking aids, required by elderly passengers in particular. A kerb-to-bus ramp allowed barrier-free access to the vehicle for passengers and their equipment.

While designed with women in mind, this project has the potential to improve safety for all users: men, gender-diverse people and people from diverse socioeconomic and regional backgrounds.

Method: co-creation and participatory research

The LivingLab used co-creation and co-design, also known as participatory research, to investigate different user groups and their needs when designing the new mobility services. These methods enable new services to be conceptualised from customer perspectives and include a gender-sensitive framework. This method added new insights into the relevant functionalities, i.e. what services are needed; the configuration of vehicles and infrastructures, i.e. vehicle features and routes; and relevant ICT access to the service.

To apply this participatory research within the LivingLab, 'typical representatives' (similar to personas) of the overall population were developed to stimulate discussion among those involved in the co-design workshops (Pruitt and Adlin, 2006; Baumann, 2010; Miaskiewicz and Kozar, 2011; Beyer and Müller, 2019). The goal was to understand the specific needs, contexts, and conditions of users throughout the broader population (not

The persona profile of 'Ingrid Henke'.

just the participants themselves) and across gender groups in particular. These 'typical representatives' emerged from a survey of the population to be served. The people participating in the co-design workshops developed services (including vehicles) for these 'typical representatives'. For example, the senior citizen 'Ingrid Henke' represented elderly people who own a car but use it only if there is no alternative, and 'Hans Lehmann' represented disabled people who depend on barrier-free public transport to get to their workplace.

One advantage of this co-design approach was the immediate integration into the research and development process of both a new mobility option and accessibility/access to the new option. Another advantage was that, from the outset, the engineers and designers understood the system as a whole from the perspective of how individuals use it in their everyday lives.

Improving and enhancing options for public transport and supplementing services may also help reduce environmental harm in cities. The German Environmental Agency (UBA) has analysed greenhouse gas and air pollutant emissions per person-kilometre. The results indicate, for instance, that car users in Germany emit 0.004 g particulate matter per person-km (given the average occupancy of 1.5 persons per car) versus. 0.000 g for public transport users in cities (UBA, 2019). Enhancing the usability of public transport helps cities and regions meet their environmental goals.

Emission	Mode						
	Car	Aeroplane (inland)	Railway (long distance)	Coach (long distance)	Railway (local transport)	Public bus	Light rail and metro
Greenhouse gases	147	230	32	29	58	80	58
Carbon monoxide	1.00	0.48	0.02	0.02	0.04	0.06	0.04
Volatile hydrocarbons	0.14	0.13	0.00	0.01	0.01	0.03	0.00
Nitric oxide	0.43	1.01	0.04	0.06	0.20	0.32	0.05
Particulate matter	0.004	0.011	0.000	0.001	0.002	0.003	0.000
Average occupation rate	1.5 persons per car	71 %	56 %	55 %	28 %	19 %	19 %

Gendered innovation 3:
Mobility for new urban lifestyles

The share of heavy users of public transport is particularly large among the urban population. To serve existing customers and to attract new customers, public transport operators such as BVG in Berlin (Germany) are supplementing conventional mass transit with individual ride-hailing services. These services are designed to ease the last mile from the mass transit terminus to the final destination, or to allow door-to-door transport. These new services respond to customer comfort and safety needs. For example, passengers need to get home safely at night even when their route requires travel through unsafe areas.

The services started in 2019 on an experimental basis and will be scaled up to cover all of Berlin in 2020. Although not suited to rural areas or parts of the city far from the centre, these mobility services are an ideal way to connect city centres with suburbs and outer areas. Commercial providers such as Uber are also responding with new features to enhance user safety. Uber's 'follow my ride' feature allows friends and family to track a user's trip.

Gendered innovation 4:
A toolbox for gender-sensitive decision-making

Gender-sensitive research combines quantitative methods such as data mining and analytics with qualitative methods such as surveys, focus groups or individual in-depth interviews aimed at understanding user needs, preferences, barriers or objections.

The use of quantitative and qualitative methods is featured in the H2020-funded project Revealing fair and actionable knowledge from data to support women's inclusion in transport systems (Diamond, 2018–2021; see Diamond 2020), which seeks to enhance fairness in transport. Fairness, here, is defined as a state in which people are treated similarly, unimpeded by prejudices or unnecessary distinctions or barriers, unless these are well understood and justified. Diamond is aimed specifically at supporting gender inclusion in current and future transport systems.

Starting from specific use cases, such as vehicle sharing and automated vehicles, Diamond collects data that can be fed into a self-diagnostic tool (Decision Support System) that can be used by transportation system engineers to understand individual user characteristics such as gender, age, ethnicity, religion, family, disability and socioeconomic status. Designers can then develop fairness measures. For vehicle sharing, for example, knowing what percentage of shared vehicles are used by elderly women, young men, gender-diverse individuals or persons in need of physical assistance helps planners make gender-sensitive decisions about fleet distribution across geographical locations.

Gendered innovation 5:
Observatory for gender-smart transport

The H2020-funded Transport innovation gender observatory (TInnGO) project (see TinnGO, 2020) is establishing a pan-European observatory to provide a nexus or clearing house for data collection and analysis supporting gender-sensitive and diversity-sensitive smart mobility. TInnGO is applying tools such as GIA and

gender action planning to smart mobility. Their goal is to develop recommendations that help address gender issues among diverse groups in a Europe-wide framework for smart mobility.

Conclusion

Numerous projects based in Europe are developing methods to integrate gender-sensitive and diversity-sensitive data into the design and development of smart mobility. These methods include co-creation and participatory research that gathers feedback from users early in the design process in order to understand the range of their needs. They also include quantitative and qualitative methods designed to promote fair, safe and efficient transportation.

>> Next Steps

▶ Implement the emerging tools that incorporate gender-sensitive and diversity-sensitive approaches into all smart mobility projects.

▶ Provide guidelines for gender-sensitive and diversity-sensitive data collection, and the assessment of data collected on user attitudes and behaviours.

▶ Provide guidelines for gender-sensitive and diversity-sensitive collection and assessment of national travel survey data.

▶ Implement improved consideration of gender equity and diversity equity for smart mobility applications and their assessment in smart urban mobility plans.

▶ Investigate how experienced or feared bullying or violence affects the travel behaviour of women, the elderly, and transgender and gender non-conforming individuals (Lubitow et al., 2017), and develop countermeasures.

Recommendations for future basic research

▶ Include gender analysis as an integral part of socioeconomic and behavioural research for innovation in the field of mobility.

▶ Integrate gender analysis in research on mobility needs and travel patterns. Consider the mobility options and local environments – including infrastructures for daily household needs, childcare, education and employment – available to different groups, such as the elderly, women, men and gender non-conforming people.

▶ Design new services using participatory methods that integrate gender analysis.

▶ Research mobility-related infrastructures in built-up environments using gender analysis and participatory methods.

▶ Research mobility behaviour and mobility environments, including causal relationships between exposure to stressors and health impacts.

▶ Develop innovative large-scale experimental approaches that address the role of mobility in the context of social challenges.

▶ Research the integration of digital and physical aspects from a gender-sensitive perspective to develop new solutions.

Policy recommendations

▶ Disseminate existing research and best practices.

▶ Create guidelines and manuals to improve gender-sensitive planning for new services and the adaptation of existing services.

▶ Promote the engagement of relevant stakeholders to support gender-sensitive mobility policies in the city and beyond.

▶ Support experimentation at local and regional levels.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Cluster 5: Climate, energy and mobility

▶ Analyse gender specific requirements for the improvement of quality of life through demand-based, zero carbon, accessible and safe mobility, and integrate these gender-specific factors into the development of vehicles, infrastructures and services.

▶ Develop technologies and services that empower women to enhance individual capabilities and satisfaction with decision-making for sustainable mobility choices.

▶ Develop and enhance methods of citizens' engagement in long-term energy planning, transport investment planning and transition policies. Ensure that these methods explicitly address gender issues.

▶ Consider gender dimensions when developing and defining new governance models for accessible, smart mobility services for all.

▶ Analyse and consider human factors through the lens of gender, including societal behaviours, new mobility patterns, perception of (ICT-based) information, situational awareness and interaction with automation.

▶ Make gender analysis central to the systemic transformation of transport and mobility.

Mission areas

The board of the EU Mission for climate-neutral and smart cities has declared 100 climate-neutral cities in Europe a target for 2030, and it

emphasises 'by citizens and for citizens' (European Commission, 2020). Within the framework of a CCC (between the city, the European Commission and the national level), strategies for achieving climate-neutral goals will be city-specific. The focus on the citizen requires planners to include all genders in a way that effectively connects each individual with their city.

The June 2020 report on climate-neutral cities (European Commission, 2020) emphasises that cities can achieve climate-neutrality only if citizens become agents of change through bottom-up initiatives and innovation and through new forms of governance. It declares that holistic and transformative missions aiming to create climate-neutral cities, based on citizens' participation and social inclusiveness, can help the EU progress towards achieving multiple SDGs, including equality. The CCC will need to ensure that gender issues are an explicit part of designing and implementing these transformation processes.

Partnerships

Relevant candidates for European partnerships will relate to quality of life in terms of where and how people live, and also to technologies that aim to augment people's well-being. These recommendations are important for the following partnerships:

- ▶ Sustainable, Smart and Inclusive Cities and Communities
- ▶ Towards Zero-Emission Road Transport (2ZERO)
- ▶ Mobility and Safety for Automated Road Transport (MOSART)
- ▶ People-Centric Sustainable Built Environment.

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WASTE MANAGEMENT: CO-CREATION AND PARTICIPATORY DESIGN

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The challenge

Sustainable waste management aims to minimise waste production and reduce greenhouse gas emissions. Currently, waste constitutes 3 % of the European Union's greenhouse gas emissions (European Commission, 2018) and 0.1 % of global emissions (Ritschie and Roser, 2019). These global data are probably inaccurate, since many countries are not able to calculate their waste emissions.

Scholars point out that 'gender issues have been poorly understood and largely neglected in waste management and most other environmental and technical sectors' (Buckingham and Perello, 2019, p. 11). This case study will analyse EU Horizon 2020 research that has successfully addressed these issues and will highlight how sex and gender analysis can lead to innovation in this sector.

Gendered innovation 1:
Collecting data on gendered waste behaviours and intervening to change user behaviours

Pioneering Horizon 2020 projects have tried to mainstream gender into all phases of waste management: design, structure, implementation and evaluation (UrBAN-WASTE, 2020; Ecosistemi et al., 2019; Waste4Think, 2019). Data

highlight gender inequities in the field of waste management. Most waste management employees are still men, for example (OECD, n.d.; Table 1 below). Women, by contrast, do somewhat more unpaid labour in household waste management. For example, 73 % of women versus 68 % of men seek to reduce waste and take time to separate waste (European Commission, 2014; Buckingham and Perello, 2019; Table 2 below).

COUNTRY	MALE (%)	FEMALE (%)
Denmark	96,000 (72.2%)	37,000 (27.8%)
Greece	212,000 (77.4%)	62,000 (22,6%)
Italy	2,015,000 (87.5%)	287,000 (12.5%)
Portugal	286,000 (78.4%)	79,000 (21.6%)
Spain	1,128,000 (84.2%)	244,000 (17.8%)

Numbers and percentages of men and women employed in the water supply, sewerage, and waste management and remediation sectors in 2017
Source: Buckingham and Perello (2019; from OECD, 2017), with permission

Gender	% reduce or separate waste	% reduce consumption	Avoids food waste	Avoids over-packaged goods	Drinks tap rather than bottled water	Thinks reducing waste is not important
Female	73	59	85	65	70	12
Male	68	52	81	59	63	20

Gendered attitudes to and behaviours in avoiding waste in 2014, 2017
Source: Buckingham and Perello (2019; from European Commission, 2014), with permission

Method: participatory methods using the UrBAN-WASTE app

Gendered use of the waste app.
Source: Buckingham and Perello (2019), with permission

UrBAN-WASTE is an interactive mobile application to promote more sustainable waste behaviours. The H2020-funded UrBAN-WASTE project (UrBAN-WASTE, 2020) focuses on reducing waste in 11 tourist destinations, such as Florence, Lisbon and Nice, but the approach is transferable to other cities. The app is based on a gamification model in which the user's good practices in recycling, avoiding food waste and refilling reusable water bottles (among others) are rewarded with points.
Users are scored on the correct use of waste receptacles and on how much they promote the UrBAN-WASTE app on social media. Users with high scores receive gifts or services from cities or participating vendors, such as restaurants. Interactive maps show the location of waste resources (recycling bins, receptacles) and water fountains (to refill reusable water bottles).

The app also includes tips for sustainable behaviours, useful links (waste collection times, general rules) and the option to report to the city any problems that users encounter. The prototype design included gender perspectives from gender experts, gender-sensitive co-design with the whole project team and gender as a category in the monitoring software. Evaluations confirmed that the app helped users improve their waste management behaviours and helped cities facilitate more responsible user behaviour.
Despite the attention given to gender in the development of the UrBAN-WASTE app, data analysis showed that it attracted more male users, which is typical of games and electronics in general (Horelli and Wallin, 2013; EIGE, 2016). This project could have been improved if researchers had used participatory methods to better capture

user behaviours. It is possible that a completely redesigned user interface is needed to ensure parity in user uptake. It is also possible that engaging more men is a positive outcome, since women are already more motivated to reduce waste.

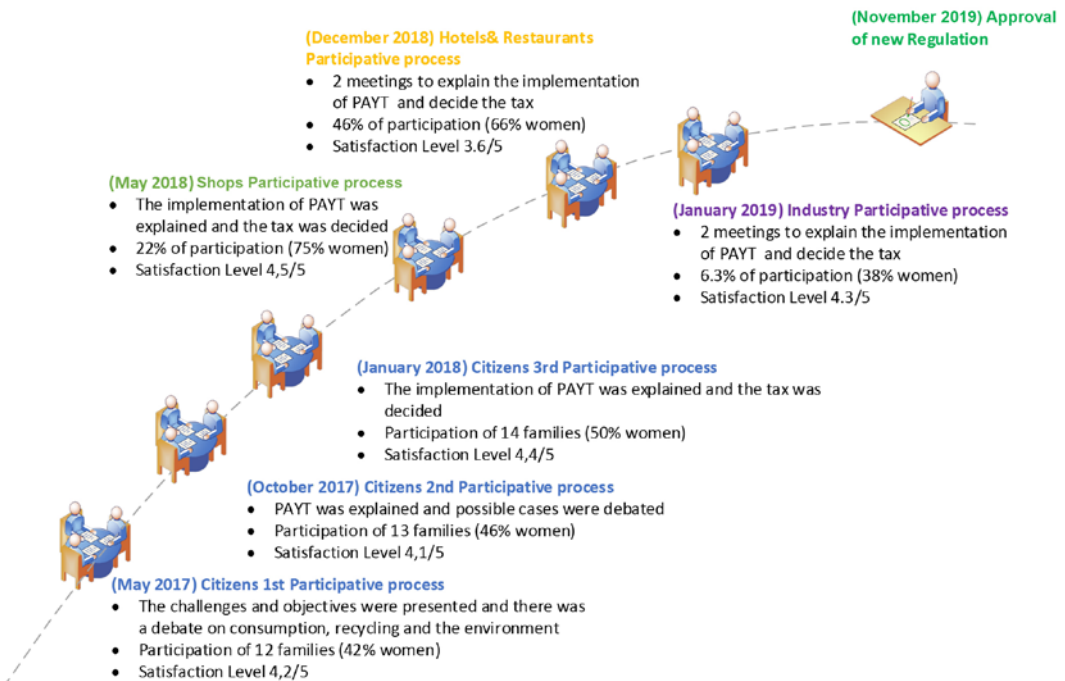For data collection, the UrBAN-WASTE app project included the non-binary gender category 'other'. For this project, the designers expected people who do not identify as a woman or a man to choose the 'other' category. It is possible that in the future better designations will be devised (see 'Asking about gender and sex in surveys' in Annex B). One additional possibility could be 'diverse', which is a third category used for the collection of socioeconomic statistical data, for example in Germany.

Gendered innovation 2:

Using participatory gender mainstreaming to collect sex-disaggregated data on waste behaviours and to foster women's participation in waste management

To reduce waste and improve reuse and recycling rates, a number of municipalities have developed programmes that include:

- monitoring systems for dustbins/trash cans and lorries/trucks;

- decision-making information systems for short-term and long-term planning;

- economic instruments (project Pay as you throw, PAYT; PAYT, 2005);

- incentives (H2020-funded project Waste4Think; see Waste4Think, 2020).

(December 2018) Hotels& Restaurants Participative process
- 2 meetings to explain the implementation of PAYT and decide the tax
- 46% of participation (66% women)
- Satisfaction Level 3.6/5

(November 2019) Approval of new Regulation

(May 2018) Shops Participative process
- The implementation of PAYT was explained and the tax was decided
- 22% of participation (75% women)
- Satisfaction Level 4,5/5

(January 2019) Industry Participative process
- 2 meetings to explain the implementation of PAYT and decide the tax
- 6.3% of participation (38% women)
- Satisfaction Level 4.3/5

(January 2018) Citizens 3rd Participative process
- The implementation of PAYT was explained and the tax was decided
- Participation of 14 families (50% women)
- Satisfaction Level 4,4/5

(October 2017) Citizens 2nd Participative process
- PAYT was explained and possible cases were debated
- Participation of 13 families (46% women)
- Satisfaction Level 4,1/5

(May 2017) Citizens 1st Participative process
- The challenges and objectives were presented and there was a debate on consumption, recycling and the environment
- Participation of 12 families (42% women)
- Satisfaction Level 4,2/5

Participatory process.
Source: Waste4Think (2019), with permission

Take for example Zamudio (Basque Country, Spain), a community with around 3 200 residents. The PAYT project developed there included seven industrial areas and the largest science and technology park in the province. Industrial waste represented 68 % of the total waste generated in the municipality. During the 2-year project, the city organised workshops with citizens and representatives from the service sector and industry to discuss the regulations and rates governing PAYT. The participants could also evaluate the quality of the workshops (satisfaction level 5, very good). One objective was to foster women's participation in these workshops to increase their representation in the field of waste management.

Method: information on waste generation patterns via citizen cards (Waste4Think)

In the particular case of Zamudio, waste generation is monitored through the use of electronic locks on containers with chambers that restrict waste volume. Users are identified by their citizen cards: cards they use for other municipal services. PAYT is calculated for each household when the different containers are opened (e.g. residual, glass, plastic or organic waste). Each member of a household has their own citizen card so that use can be analysed by sex and age (Waste4Think, 2019).

Example of information collected for Ways2Sort game. Source: Waste4Think (2019), with permission

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Method: behaviour analysis data from serious games and digital teaching units (Waste4Think)

One of these projects is a smartphone game called Ways2Sort, which teaches users how to sort 200 waste items of different types, e.g. glass or biowaste. Preliminary data about sex and age, as well as information about habits and previous knowledge, were collected during citizen card logins. To foster citizen participation, tests were performed for particular target groups (schoolchildren, university students, professionals in the sector, etc.).

Conclusions

Mainstreaming gender analysis in waste management means considering gender at every stage of the process. Important steps to foster gender analysis include:

▸ raising gender awareness in this field of research and practice;

▸ gathering sex-disaggregated and gender-disaggregated data in the waste management sector;

▸ gathering data on gendered attitudes and behaviours with respect to waste;

▸ employing gender-sensitive participatory methods.

The European Union and the Horizon 2020 project have shown that integrating gender into urban policies and planning processes for waste management will help reduce waste and encourage a circular economy.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Waste management addresses local and global challenges and the SDGs, especially SDG 5 (gender equality), SDG 11 (responsible consumption and production) and SDG 13 (climate action). Sustainable waste management serves as a foundation for a circular economy and one of the main building blocks for the European Green Deal.

Cluster 5: Climate, energy and mobility

Advance climate science and solutions for a climate-neutral and resilient society

Profound knowledge of gendered issues in waste management contributes to understanding gender in waste generation behaviours and how to intervene to change those behaviours. This knowledge contributes to decision-making tools at different governance levels (from local to global) and to effective waste treatment that serves as a pillar of gendered climate-neutral and smart cities.

Develop sustainable infrastructure, services and systems for smart and sustainable communities and cities

Sustainable waste management is a key factor for smart gendered thinking about sustainable communities and cities. Gendered knowledge can contribute to better solutions for city/district management for waste systems and assist the EU in achieving its low-carbon goals.

Empower citizens to engage in the transition to a decarbonised society

Co-creation and co-design can empower all citizens to engage in the transition to climate-neutral cities (see 'Co-creation and participatory research' in Annex B). In particular, co-creation and co-design foster women's participation in waste management, which is currently dominated by men.

Mission area: 100 climate-neutral cities by 2030

Research has identified the potential and added value of a gendered perspective for minimising resource inputs, waste and carbon emissions in a circular economy. Waste treatment is a key indicator for measuring and monitoring greenhouse gas emissions. In this case, a gendered approach leads to a better understanding of citizen engagement in waste management, which is necessary to achieve gender-inclusive climate-neutral cities. A gender-sensitive approach can foster the engagement of different (gender) groups of citizens and experts (see also 'Intersectional approaches' and 'Gender impact assessment' in Annex B).

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QUALITY URBAN SPACES: GENDER IMPACT ASSESSMENT

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The challenge

The physical features of urban space are key elements for supporting everyday life for all citizens independent of gender, age, socioeconomic status, race, physical ability, ethnicity or other personal circumstances. When urban spaces are unsafe or inadequate, everybody suffers. Issues include narrow, poorly maintained or non-existent pavements; scarce or remote healthcare, educational, cultural or sports facilities, shops and workplaces; and scarce or unsafe playgrounds and green areas. The lives of some people, including children, elderly people and caregivers, can become especially difficult and limited (Bernard Van Leer Foundation, 2018; Unicef, 2018).

While men are increasingly taking up more caring responsibilities (O'Brien and Shemilt, 2003), women remain the main caregivers. In 10 EU countries, in households with parents living as a different-sex couple with small children, women perform an average of 2 hours and 21 minutes of childcare per day compared with men's 59 minutes (European Communities, 2004). This pattern holds in the United States as well. In 2018, the average US mother spent 1 hour and 49 minutes caring for and helping children in her household, more than twice the average US father's 52 minutes (United States Bureau of Labor Statistics, 2019). Single-parent households constitute a growing percentage of all households, and the parent is typically a woman. These households face additional difficulties in combining paid employment with caring duties and are among those in most need of support.

Where urban design is inadequate, children will not have the chance to grow up safely while exploring new boundaries and gaining autonomy. Elderly people will not be able to lead an active autonomous life. Mothers and other caregivers will struggle to balance paid employment with their care responsibilities. Lower-income people, as well as racial and ethnic minorities, who are often concentrated in lower-income areas, will live in neighbourhoods with comparatively poor urban spaces because of patterns of spatial segregation in cities around the world. As a result, women, children and elderly people from these groups will endure comparatively greater life limitations because of poor-quality urban spaces. While transgender and gender-diverse individuals suffer bullying and violence in public spaces (Eisenberg et al., 2019), the extent to which this can be addressed through urban design is limited.

Quality urban spaces designed to respond to the specific everyday life needs of women, children and elderly people are not, however, the norm. Suburban, single-family, low-density areas, typical of North American cities, lack sufficient density to ensure that facilities used on a daily basis, such as schools, doctors offices or sports fields, are within walking distance, which would allow young people to access them unaccompanied. In addition, often there are insufficient passers-by in these areas to provide the informal supervision that affords a sense of safety.

At the same time, cities in which high-density development and residential neighbourhoods are the norm often lack open green areas and playgrounds that can be used safely by unaccompanied young people. In suburban areas, such outdoor spaces are on private property, as part of patios or gardens in residential developments. In high-density neighbourhoods, green space is often missing, and children lack opportunities for play and exercise. Both children and adults often lack opportunities for social interaction and a sense of community.

In the developing world, all these problems coalesce and are often more severe, with a lack of walkable streets, public spaces, playgrounds, easily accessible facilities and amenities, and

basic urban infrastructure such as pavements or even lighting (NIUA, 2017).

Improving the quality of urban spaces by looking at the specific needs of children, elderly people and caregivers will create better urban environments for everyone. Improving the quality of urban spaces in ways that provide better support for these groups is a challenge that will require design solutions and measures tailored to both low-density and high-density environments, taking into account the economic capacities and constraints of cities and countries.

The main physical characteristics of streets and public spaces that support the daily lives of children and their families include (ODI, 2017; Gehl Institute, 2018; Krishnamurthy et al., 2018; NACTO, 2018; Sánchez de Madariaga and Neuman, 2020):

▸ walkable streets with reduced traffic that enable and encourage active independent mobility for young people, elderly people and everyone else, and reduce the adverse health effects of pollution (particularly severe for children, because they breathe at the height of exhaust pipes and their bodies are still maturing);

▸ formal and informal natural public spaces for outdoor play that encourage the physical, psychological, emotional and mental development of children and support their caregivers;

▸ formal and informal indoor and outdoor community spaces that create opportunities for social connectedness, promote a sense of ownership, and support the development of agency and the decision-making capabilities of young people;

▸ sufficiently dense and mixed-use spaces to facilitate undertaking daily activities within walking distance from home, including independent school attendance, shopping for groceries, seeing a doctor and sport.

Gendered innovation 1:
Building child-friendly and family-friendly streets and public spaces

Numerous initiatives around the world have improved public spaces for children and their families.

Japan provides a striking example of how cities can develop child-friendly routes to school. Unlike in most countries today, Japanese children are expected to go to school on their own from a very young age, either using public transport or on foot. Both schools and local governments work together to plan, design and build physical features of pavements and streets along children's school routes. Physical improvements can include one or several of the following (Krysiak, 2019): relocating pedestrian crossings; longer green lights for pedestrians; temporary traffic closures near schools at peak times; signs to alert drivers that there are schoolchildren nearby; pictograms such as small feet painted at crossings to remind children to watch out for traffic.

The Bernard van Leer Foundation, a Dutch organisation, works with cities around the world to improve urban space and streets for toddlers and children through its Urban95 programme (Bernard van Leer Foundation, 2018). In Lima, for instance, Urban95 has developed child-friendly routes to preschool, bringing together three local governments – the municipalities of Carabayllo, Comas and San Juan de Miraflores – with non-governmental organisations. The project, launched in 2018, addressed the travel needs of toddlers and parents living in the hilly neighbourhood of Alto Perú who chose to take long and expensive taxi trips because the shortest pedestrian route was dangerously steep, rubbish-ridden and uneven. The project involved cleaning up rubbish, building retaining walls, installing double handrails at adult and toddler heights, planting trees and vegetation, and adding seating and rest areas.

In 2002 the city of Vienna developed a specific pilot project to improve public space in Mariahilf (Irschik and Kail, 2013), a small and dense central district with narrow streets and some vertical inclines of up to 31 metres. Before

the intervention, Mariahilf had about 50 public stairways and flights of steps, more than 30 of which were without ramps; about 25 % of all pavements were less than 2 metres wide, narrower than the minimum width needed for walking in pairs; and about 50 % of all intersections were difficult for pedestrians to cross. The project sought to reduce these architectural barriers and improve safety. This involved developing a checklist for street design to address both technical standards for pedestrian movement and social factors such as pedestrian routes to major destinations in the district. As a result, planners: widened more than 1 000 metres of pavement; improved more than 60 intersections that reduced pedestrian crossing times; implemented barrier-free design throughout the neighbourhood; installed numerous seating facilities; installed new lighting in 26 spots; and refurbished three public squares.

In the United States, the non-profit organisation KaBOOM! works to support child development in low-income areas by creating opportunities for play in public space for children in collaboration with cities around the country. In collaboration with the William Penn Foundation of Philadelphia, KaBOOM! developed Play Everywhere Philly in 2018 (KaBOOM!, 2018). This is a city-wide competition awarding USD 1 million in grants for local groups working with professional designers to create interactive play installations. The interventions involve the creation of play-oriented learning features for children aged 0–8 on pavements and footpaths, at bus stops and outside business premises. These included objects, sculptures, drawings, plantings, signs, symbols, words, texts and games aimed at stimulating children's attention, involvement and imagination.

Pioneering work on women's safety was developed and carried out by Montréal and Toronto in the 1990s (Michaud, 1997). Numerous cities around the world are now implementing the methodology developed in Canada. This methodology, called exploratory safety audits, includes walking with women to determine the following safety principles (UN Women, 2011).

Principle 1: Know where you are and where you are going. Signposting.

Principle 2: See and be seen. Visibility.

Principle 3: Hear and be heard. The presence of people.

Principle 4: Be able to escape and get help. Formal surveillance and access to help.

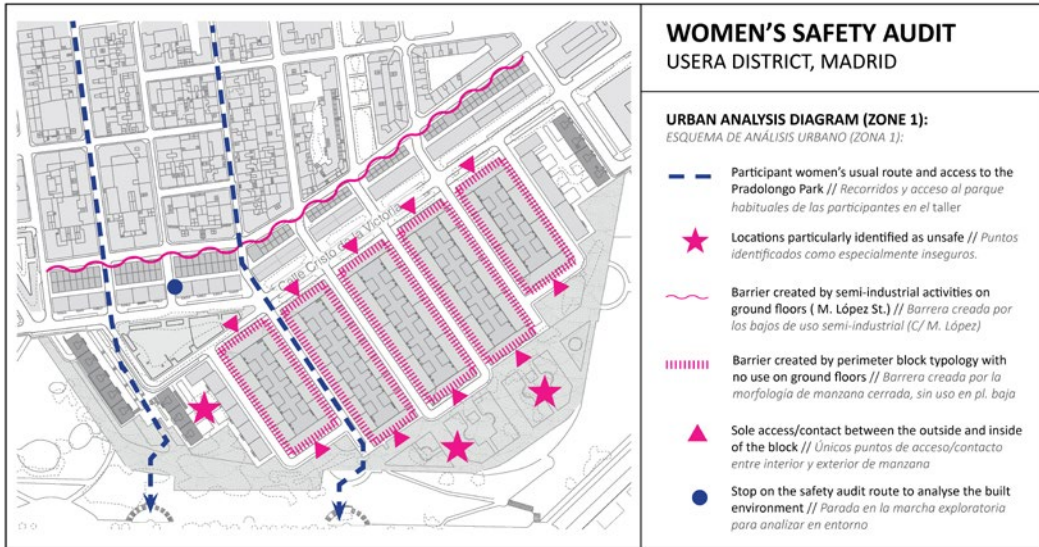Principle 5: Live in a clean and friendly environment. Spatial design and maintenance.

Principle 6: Act together. Community participation.

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Morning women's safety audit at the Pradolongo Park, Usera District, Madrid, December 2016.

Exploratory safety walks with women allow city planners to identify dangerous neighbourhoods or transportation segments (Sánchez de Madariaga, 2004). A study in the area surrounding the Pradolongo Park in the Usera district of Madrid applied this methodology through the following steps (Novella Abril, 2020): an initial workshop in which neighbourhood women worked with professional planners; the exploratory walk itself; the drafting of the report; a final workshop with the local women. The results were mapped, and specific recommendations were made to the city on where and how to improve urban design.

Analysis of pedestrian accesses in the northern section of Pradolongo Park, Usera district, Madrid, January 2017.
Source: Novella Abril (2020), with permission

Gendered innovation 2:
Building playgrounds for girls and boys of different ages

Playgrounds in residential complexes or in public spaces can be specifically designed for girls and boys of different ages as well as for elderly people. The city of Vienna redesigned several parks after a study in the mid-1990s found that the presence of girls in parks and public playgrounds decreases significantly from the age of 10, with consequences for their self-confidence and body awareness (Irschik and Kail, 2013). The internationally recognised housing complex Frauenwerkstadt, designed by Franziska Ullmann for the city of Vienna, includes a variety of open spaces specifically designed for the playing and social needs of boys and girls of different ages.

The programme 'gender-sensitive parks, sports grounds and playgrounds for children and young people in Vienna's municipal districts' involved two pilot projects and the redesign of four additional parks around the city. The objective was to explore spatial configurations that would support girls' and women's use of public space and sense of belonging. Participatory workshops with neighbourhood girls re-

vealed girls' priorities in park redesign: a facility for girls only, an area for play and sports not dominated by boys, a 'communication zone' for socialising and meeting new people, and clear division of the space into different areas offering higher and lower levels of activity and privacy (Irschik and Kail, 2013). Similar participatory workshops could be carried out with young LGBTI+ people.

Vienna's authorities then carried out a gender assessment to understand which projects could be scaled up. The evaluation consisted of a landscape analysis of 14 parks and a detailed user and spatial pattern analysis of five parks, including the two earlier pilot projects. This analysis resulted in a series of working group meetings that included representatives of the departments involved, representatives from youth services and the landscape architects for the model projects. The objective of the meetings was to develop planning recommendations for the gender-sensitive design of public parks for the city (Damyanovic et al., 2013, pp. 82–84). The most important aspects of the recommendations include safety and visibility, as well as the provision of quiet areas and areas designed for activities preferred by

girls, such as skating, volleyball and badminton. In parks with heavy use, the recommendation is to divide the larger spaces and ball game areas into smaller subareas to prevent larger areas from being occupied exclusively by the most dominant group.

Since 2007, these recommendations, along with the general park design guidelines, must be taken into account by all contractors for the city of Vienna's Department of Parks and Gardens. Girls and boys in different cities may have different preferences, but cities can use similar processes to design inclusive parks.

Method: pilot projects

Pilot projects allow urban designers and planners to test new ideas and solutions to changing social contexts, and new responses to demands on the built environment (Irschik and Kail, 2013). Through carefully designed pilots, competitions or participatory user workshops, planners can conduct small-scale experiments. From these new experiences
 knowledge is gained that can be more broadly applied to generate innovation at scale.

Method: gender impact assessments

The experience acquired through pilot projects needs to be evaluated through gender assessments of impacts in order to understand who benefits from urban design and who is left out. From the results, conclusions can be drawn about what could be relevant to broader applications. Gender impact assessments produce systematic evaluations for developing more general recommendations. Where relevant, these assessments should include intersectional variables, such as age, ethnicity, physical ability and geographical location.

Method: planning and designing guidelines and manuals

Manuals and guidelines are important policy tools used for gender mainstreaming or when the implementation of a new policy requires the acquisition of new skills and/or institutional capacity building. They provide systematic recommendations, examples of good practice, illustrations, references and checklists for professionals and officials in charge of implementation (Zibell et al., 2019).

Conclusions

Since the Second World War, cities have been designed primarily for cars, with little thought given to pedestrians. This has disproportionately affected children and elderly people, the most vulnerable groups of pedestrians, limiting their free mobility in public spaces. Most cities around the world today do not provide minimum standards for quality public spaces for many of their youngest residents. Quality safe streets and public spaces in which children can play, explore, socialise and travel autonomously are critical for their physical, psychological, and mental development. Such spaces also benefit caregivers, elderly people and gender-diverse people. Quality public spaces for young people also require consideration of gender differences in the use of public spaces at different ages. Individual projects at different urban scales and locations in cities around the world are showing how to create liveable streets and open spaces in which children can play safely, but they are still by no means the norm.

Good practices for integrating gender dimensions in urban design, as highlighted in this case study, can provide a foundation for broader policy developments. Good practice emerges from specific local cultures and urban structures, including density and urban morphology, the funding and administrative capabilities of cities, planning systems, design cultures, etc.

Future basic research

▶ Research on the interaction of children – both girls and boys – elderly people, caregivers, women, men and gender non-conforming people with their specific urban environments must be specific to local culture, local urban morphologies, and local planning cultures and systems.

▶ Research on policy processes is needed to create wider support for more systematic change. Policy processes in urban planning and design are highly context specific in terms of the urban and spatial place in which they are implemented, a country's political culture and the legal planning systems, which includes the specific operational culture, administrative system and professional approach.

Policy

▶ Disseminate existing research and good practice.

▶ Create context-specific guidelines and manuals highlighting the gender dimension for urban spaces.

▶ Develop norms and regulations that support liveable streets, public parks and playgrounds for everyone.

▶ Create institutional capacity for effective implementation.

▶ Promote alliances of different stakeholders to support coordinated policies addressing the needs of children and other vulnerable populations in the city.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Cluster 3: Civil security for society

Analyse the safety of women by age, from infancy to old age, in the following areas: urban public spaces and transportation; digital and cyberspace; migrant and refugee populations; disaster and risk management.

Cluster 5: Climate, energy and mobility

Analyse gender issues in access to energy, including the energy poverty of women, by age. Study gender dimensions of transportation services and infrastructure, and women's needs in transportation and patterns of mobility. Consider gender dimensions and women's issues in urban planning, including access to housing and employment, and the provision and location of urban facilities; quality of public spaces; and participation of women in decision-making processes and in technical teams. Analyse digital solutions free of gender bias and omissions. Consider gender issues in consumption patterns and gender dimensions to support work–life balance.

Mission area: 100 climate-neutral cities by 2020, by and for citizens

Experiments with systemic transformation towards climate neutrality and sustainability by 2030 must take into consideration gender issues, looking at how women, men, girls, boys and gender-diverse people use cities differently.

Quality streets and public spaces must respond to the different daily needs of people, and particularly of children, elderly people and their caregivers.

Partnerships: European Institute of Innovation and Technology Urban Mobility; Built environment and construction

Streets and urban public spaces are often designed and built giving priority to the needs of cars over the needs of people. Quality urban spaces require careful attention to:

▶ children, by providing spaces to grow up safely while exploring new boundaries and gaining autonomy;

▶ elderly people, by providing infrastructure to enable active autonomous lives;

▶ mothers and other caregivers, by providing high-quality, safe urban spaces and transportation systems;

▶ lower-income people, as well as racial and ethnic minorities, by desegregating cities.

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Information and communication technology (artificial intelligence, machine learning, robotics)

EXTENDED VIRTUAL REALITY: ANALYSING GENDER

The challenge

Technologies under the umbrella term XR – including VR, AR and MR – combine elements of real and virtual worlds in computer environments, human–machine interaction and electronic wearables. These techniques have applications in many areas, such as medical training (Hamza-Lup et al., 2018), construction and engineering (Sun et al., 2018) and education (Weng et al., 2018; Makransky et al., 2019).

How can these technologies be deployed to promote gender equality?

Gendered innovation 1:
Developing empathy through extended reality

Bias in general, and gender bias in particular, fuels social inequalities. Bias feeds on the tendency to favour one's own group at the expense of others. According to social psychologists (Dovidio and Gaertner, 2010), bias can be sorted into emotional bias (prejudice), cognitive bias (stereotypes) and behavioural bias (discrimination). More specifically, gender bias refers to the (conscious or unconscious) preference for or prejudice against one gender over another and has been extensively studied (FitzGerald and Hurst, 2017). Gender bias exists not solely on an individual level but also on a structural societal level (LERU, 2018).

One way to reduce biases is to enhance empathy with people who are different from us. Empathy is the ability to put yourself in someone else's shoes, both emotionally and intellectually. It is the capacity to share someone else's emotional state as well as to understand that person's thoughts and feelings (Iacoboni, 2009).

VR and AR may help us develop higher levels of empathy in specific contexts, which can, in turn, reduce implicit bias. Recent studies, for example, suggest that VR can narrow the gap between in-groups and out-groups (Maister et al., 2015). By mirroring and illuminating aspects of other people's experiences, VR provides powerful opportunities to experience the world from

the perspective of someone different from ourselves.

There may, however, also be risks: VR aimed at generating empathy (as opposed to mere sympathy) may give users a false sense of having lived someone else's experience (Bailenson, 2018), leading them to underestimate the true extent of a problem or to trivialise tragic events and painful experiences (Ramirez, 2018; Hassan, 2019). A particularly troubling example was provided by the VR experience of the Puerto Rico hurricane damage delivered by Facebook's founder, Mark Zuckerberg. Many criticised the virtual 'tour' as inappropriately light-hearted in tone and for taking advantage of Puerto Rico's devastation to promote Facebook's new VR technology (Solon, 2017).

VR has been employed successfully to generate empathy in a number of studies. One reported the use of VR to combat gender-based violence. Seinfeld et al. (2018) used immersive VR to put the perpetrators of domestic violence into the body of a victim. The experiment showed that, compared with a control group, perpetrators tended more often to misinterpret fearful faces as happy. After the virtual encounter, they showed an improved ability to recognise fearful faces. VR may be used to help modify socioperceptual processes, such as emotion recognition.

A second study reported the use of XR to overcome homophobia. VeeR VR, a large 360° virtual reality (VR/360) company in Beijing, conducted

a social experiment to enhance empathy for LG-BTI+ people. Because of the 360° feature, it was possible for people to experience the experiment from both the point of view of the LGBTI+ person and the point of view of other participants. A blindfolded young woman wearing a shirt that read 'I am a homosexual' in Chinese held out her arms, inviting passers-by to hug her. The video[10] can be viewed from her perspective, where people either hugged her or walked on, or from the perspective of the passers-by. This social experiment is part of a global partnership project aimed at changing people's attitudes to LGBTI+ people (Khosravi, 2018).

Gendered innovation 2:
Promoting gender equality through virtual reality

VR provides a technology for humans to create imaginary worlds – in this case, virtual worlds where gender equality exists, with the hope that these experiences will modify behaviours in the real world. Studies show a persistent gender gap in attitudes towards gender equality, with men showing less support for equality than women (Shu and Meagher, 2018). There is, however, variation between countries and between particular groups of men, with young men, for example, tending to support gender equality more than older men. Other factors, such as race and ethnicity, education and geographical location, also play roles.

A new study conducted by the global market research firm Ipsos and the Global Institute for Women's Leadership, King's College London, found that men tend to believe they are expected to do too much to support women's equality, because men consider gender equality to be a 'women's issue' (Elgood, 2019). Interestingly, an experiment showed that people were more likely to feel personal responsibility to solve gender inequality when exposed to inequalities in a split-sphere 360° cinematic virtual reality experience (Aitarmuto et al., 2018).

Other applications of VR also seek to enhance gender equality through imagined scenarios. The marketing firm Y & R New York recently launched a new app that creates virtual statues of significant women throughout the city (Yurieff, 2017). The project is a call to action to support the UN SDGs to achieve gender equality: it encourages developers around the world to erect statues of pioneering women in their own cities. Similarly, an AR app adds notable women to US banknotes (see figure below). Of 238 countries reviewed, 83, including the United States, feature only men on their currency. By contrast, Australia, Japan and Sweden had an equal mix of women and men. A few countries, including Belize, feature only women (Advisa, 2017).

The Notable Women project celebrates significant women by creating virtual statues and putting women's faces on US banknotes. Rosalyn Yalow, pictured here, became the second woman to be awarded the Nobel Prize in Medicine, in 1977, for the development of the radioimmunoassay. Source: Notable Women (n.d.), with permission

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10   https://h5.veer.tv/player/?vid=lgbt-free-hug-beijing-166795&start=3.448427657

Gendered innovation 3:

Improving healthcare with extended reality

XR technologies are increasingly used in healthcare to diagnose and manage patients with pain, disability, obesity, neurological dysfunction, anxiety and depression. Breast biopsy system guided by positron emission mammography allowing real-time 3D visualization of tumour lesion and needle insertion guidance for higher sampling accuracy and efficiency (Mammocare), a study funded under Horizon 2020, has developed a three-dimensional visualisation tool that makes it possible to detect small lesions in the breast that are difficult to find using conventional technologies, contributing to earlier diagnosis of breast cancer (Mammocare, 2016). Another Horizon 2020 project, Smart working environments for all ages (WorkingAge), uses AR and VR to measure older women's and men's mental and cognitive health in order to promote healthy habits in their home and work environments (WorkingAge, 2020).

Hospitals have started experiments with 360° VR headsets to relax women in the early stages of labour by immersing them in peaceful environments in order to reduce pain. Evaluations found that 77 % of the patients experienced pain relief with the VR technique (Cowles et al., 2019).

Companies are also developing registered medical XR applications. XRHealth, a certified medical VR company, has designed a product to help breast cancer patients manage hot flushes that may occur as a side effect of their treatment (Lovett, 2019). An AI trainer called Luna appears when the patient puts on the VR headset. Luna guides users through cognitive behavioural therapy and other coping mechanisms. A pilot study found that patients with breast cancer who experience hot flushes reported 50 % fewer hot flushes and night sweats after training.

Compared with women, men are less likely to engage in preventative healthcare. Their behaviour can result in poorer outcomes and increased burden on healthcare systems. VR has proven effective in triggering men's engagement in preventative healthcare, for example by prompting them to seek screening for testicular disorders (Saab et al., 2018).

Conclusions

XR mixes elements of the virtual world into our perceptions of the real world, thus enhancing the things we see, hear and feel. This case study has suggested how these technologies might prove fruitful in promoting gender equality by reducing implicit bias and enhancing empathy, in visualising what an equal society could look like, and in promoting new modes of healthcare.

>> **Next Steps**

Felnhofer et al. (2012) have suggested that women and men may differ in the way they experience virtual environments. Men reported a higher sense of spatial presence, more perceived realism and higher levels of the sense of actually being in the environment than women. Furthermore, on social VR platforms, women experience harassment and intimidation, resulting in a lack of interest in engaging with social VR platforms. Studies have also found that virtual settings tend to lack activities that women report to be of interest (Outlaw and Deckles, 2017).

Method: analysing sex, analysing gender

'Extended virtual reality' refers to technologies such as VR, AR and MR, which incorporate elements of the virtual world into our real world, thus enhancing the things we see, hear and feel. These technologies may prove fruitful in promoting gender equality; however, they also come with risks. Research shows that women, men and gender-diverse people may differ in how they experience virtual environments. These potential sex and gender differences need to be taken into account in the development and testing of prototypes.

Women are more than twice as likely as men to feel unwell from using VR, with symptoms such as pallor, sweating, increased heartrate, drowsiness, disorientation and general discomfort (Munafo et al., 2017; Al Zayer et al., 2019). These symptoms may be due to conflict between the body's visual and vestibular (inner ear) systems, resulting in greater sensitivity in women. Reducing field of view in navigation is a common strategy to reduce VR sickness, as it has been found to mitigate the visual/vestibular conflict (Al Zayer et al., 2019). Studies suggest, however, that reducing field of view can impede spatial navigation performance, which may be a problem, since women tend to use landmarks to navigate to a higher degree than men. Thus, restricting the field of view may impede women's spatial navigation performance.

To sum up, it is important to develop virtual settings in a sex-sensitive and gender-sensitive way, applying sex and gender analyses that include both women and men in the development and testing of prototypes.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

In order to achieve this, it is important to take into account how these new technologies, such as VR, affect women and men differently. The evidence from research in this area indicates the need to consider women and men separately in the development of VR technologies because of existing sex differences in anthropometrics, motion patterns, etc.

Cluster 4: Digital, industry and space

The use of VR in industry has flourished in recent decades and is especially useful for investigating human–product interaction to evaluate visibility in the context of motion and interaction in the automotive, space and military industries, for example. Simulating product function using VR helps to forecast future functional challenges. A key targeted impact in the strategic plan for Horizon Europe, 'A Europe fit for the digital age', is increased inclusiveness by helping industry provide attractive and creative jobs in Europe aimed at developing new technologies.

Mission areas

The Mission Board for Climate-neutral and Smart Cities states that the climate emergency must be tackled by engaging citizens who are users, producers, consumers and owners. It has been well documented in research that men and women differ in terms of their engagement and behaviour related to climate change, with men tending to demonstrate less engagement and fewer behavioural changes (see case study 'Waste management'). In the quest to change this, VR has proven successful in sensitising and moving people to action.

Partnerships

European Partnership on Artificial Intelligence, Data and Robotics

To deliver the greatest benefit to Europe from AI, data, robotics and related applications, such as virtual reality, this partnership will drive innovation, acceptance and uptake of these technologies. The partnership will boost new markets and applications, and attract investment, by creating technical, economic and societal value for business, citizens and the environment.

Historically, new technology has been developed and implemented primarily in male-dominated sectors and by men. This tends to hold also for emerging technologies, resulting in a lack of women in these fields as well as a lack of analysis of sex and/or gender aspects affecting the development, implementation and use of new technologies. To deliver the greatest benefits to Europe, this has to be taken into account in the formation of partnerships as well as in the formulations of challenges to be met.

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FACIAL RECOGNITION: ANALYSING GENDER AND INTERSECTIONALITY IN MACHINE LEARNING

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The challenge

FRSs can identify people in crowds, analyse emotion and detect gender, age, race, sexual orientation, facial characteristics, etc. These systems are employed in many areas, e.g. hiring, authorising payments, security, surveillance or unlocking phones. Despite efforts by both academic and industrial researchers to improve reliability and robustness, recent studies demonstrate that these systems can discriminate based on characteristics such as race and gender and their intersections (Buolamwini and Gebru, 2018). In response, national governments, companies and academic researchers are debating the ethics and legality of facial recognition. One point is to enhance the accuracy and fairness of the technology itself; another is to evaluate its use and regulate deployment through carefully implemented policies.

Method: analysing gender and intersectionality in machine learning

Bias in ML is multifaceted and can result from data collection, or from data preparation and model selection. In the first case, the data may contain human bias. For example, a dataset populated with men and lighter-skinned individuals will misidentify darker-skinned females at higher rates. This is an example of intersectional bias, whereby different types of discrimination amplify negative effects for an individual or group. 'Intersectionality' refers to intersecting categories such as ethnicity, age, socioeconomic status, sexual orientation and geographical location that affect individual or group identities, experiences and opportunities.
Bias may also be introduced during data preparation and model selection, which involves selecting attributes that the algorithm should consider or ignore, such as facial cosmetics or the faces of transgender individuals during transition.

Gendered innovation 1:
Understanding discrimination in facial recognition

To understand discrimination in FRSs, it is important to understand the differences between face detection, facial attribute classification, facial recognition, face verification and facial identification.

Face detection can occur without facial recognition; however, facial recognition does not work without face detection. Face detection differentiates a human face from other objects in an image or video. Face detection systems have repeatedly been shown to fail for darker-skinned individuals (Buolamwini, 2017). For example, early versions of the statistical image-labelling algorithm used by Google Photos classified darker-skinned people as gorillas (Garcia, 2016). If this first step fails, FRSs fail.

Facial attribute classification labels facial attributes such as gender, age, ethnicity, the presence of a beard or a hat, or even emotions. For emotions, a review of online recognition application programming interfaces showed that

over 50 % of the systems used facial expressions to define emotions (Doerrfeld, 2015). To work, these models must be trained on datasets that are representative of the target population. Models trained on mature adults, for example, will not perform well on young people (Howard et al., 2017).

Facial recognition identifies a unique individual by comparing an image of that person to their known facial contours. One type of facial recognition is **verification**, often used to unlock a phone or to validate the identity of someone crossing an international border (see the EU-funded Horizon 2020 project Intelligent portable border control system (iBorderCtrl); see iBorderCtrl, 2017). These solutions are designed to decrease processing time. If, however, the FRSs are not trained sufficiently, for example on darker-skinned women (Buolamwini and Gebru, 2018) or transgender faces (Keyes, 2018), the technologies will fail for them. The other type of facial recognition is **facial identification**, which matches the face of a person of interest to a database of faces. This technology is often used for missing persons or criminal cases.
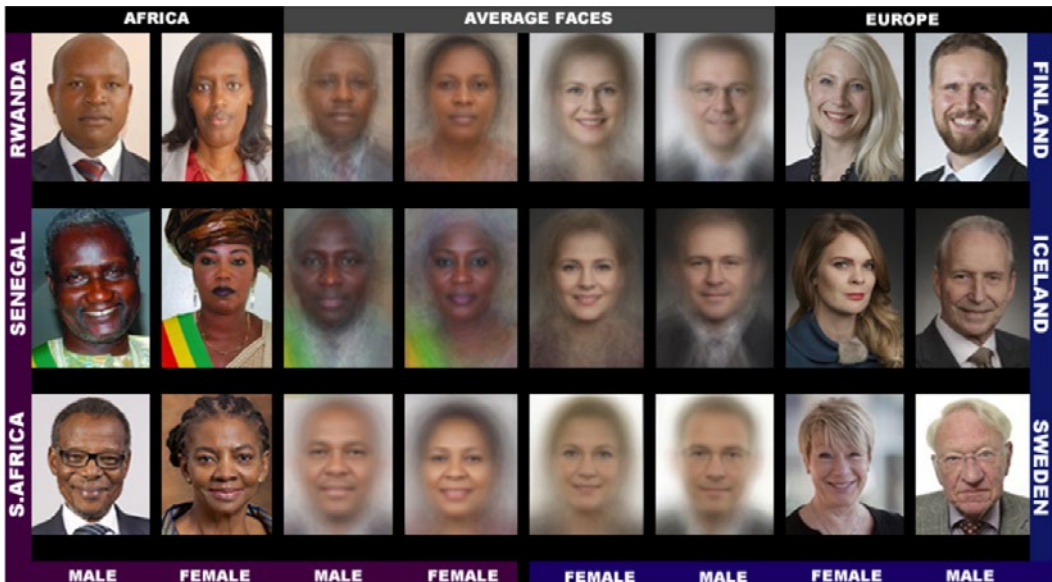
Gendered innovation 2:
Creating intersectional training datasets

The accuracy of FRSs is determined by the set of images or videos collected for testing. For the FRSs to perform well, training data must be sufficiently broad and diverse to enable the predictive model to accurately identify faces in a variety of contexts.

Zhao et al. (2017) found that, when photographs depict a man in a kitchen, automated image captioning algorithms systematically misidentify the individual as a woman, in part because training sets portray women in cooking contexts 33 % more frequently than men. The trained model amplified this disparity from 33 % to 68 % during testing. It is crucial to get the training data right.

In the now well-known Gender Shades study, Buolamwini and Gebru (2018) measured the accuracy of commercial gender classification systems from Microsoft, IBM and Face++, and found that darker-skinned women were often misclassified. Systems performed better on men's faces than on women's faces, and all systems performed better on lighter than darker

Example images and average faces from the new dataset, which includes women and men of darker and lighter skin drawn from Members of Parliament from six countries.
Source: Buolamwini and Gebru (2018), with permission

skin. Error rates were 35 % for darker-skinned women, 12 % for darker-skinned men, 7 % for lighter-skinned women and less than 1 % for lighter-skinned men.

To overcome these problems, the team developed and labelled an intersectional dataset to test gender and race classification performance on four subgroups: darker-skinned women, darker-skinned men, lighter-skinned women and lighter-skinned men. Since race and ethnicity labels are culturally specific, the team used skin shade to measure dataset diversity (Cook et al., 2019). Their dataset consisted of 1 270 images from three African countries (Rwanda, Senegal and South Africa) and three European countries (Finland, Iceland and Sweden).

An update to Gender Shades retested the three commercial systems previously examined and expanded the review to include Amazon's Rekognition and a new system from a small AI company called Kairos. They found that IBM, Face++ and Microsoft had all improved their gender classification accuracy for darker-skinned women, with Microsoft reducing its error rate to below 2 % (Raji and Buolamwini, 2019). Amazon's and Kairos's platforms, however, had accuracy gaps of 31 % and 23 %, respectively, between lighter-skinned men and darker-skinned women.

IBM Research has recently released a large dataset called Diversity in Faces. Its goal is to advance the study of fairness and accuracy in FRSs (Smith, 2019).

Gender Shades 2018

	Darker Male	Darker Female	Lighter Male	Lighter Female	Largest Gap
IBM	88.0%	65.3%	99.7%	92.9%	34.4%
Face++	99.3%	65.5%	99.2%	94.0%	33.8%
Microsoft	94.0%	79.2%	100.0%	98.3%	20.8%

Actionable Auditing 2019

	Darker Male	Darker Female	Lighter Male	Lighter Female	Largest Gap
Amazon	98.7%	68.6%	100.0%	92.9%	31.4%
Kairos	98.7%	77.5%	100.0%	93.6%	22.5%
IBM	99.4%	83.0%	99.7%	97.6%	16.7%
Face++	98.7%	95.9%	99.5%	99.0%	3.6%
Microsoft	99.7%	98.5%	100.0%	99.7%	1.5%

Accuracy in intersectional classification.

Sources: Data from Buolamwini and Gebru (2018) and Raji and Buolamwini (2019)

Establishing parameters for a diverse set of faces

Cosmetics

Wearing makeup has been a popular practice throughout history and in numerous cultures. Although men's use of cosmetics is on the rise, women use makeup more. Loegel et al. (2017) report that women use makeup to give themselves an image that is compatible with cultural norms of femininity.

Facial cosmetics reduce the accuracy of both commercial and academic facial recognition methods by up to 76.21 % (Dantcheva et al., 2012; Chen et al., 2016). One reason is that makeup has not been established as a parameter in publicly available face databases (Eckert et al., 2013). One proposal for developing FRSs that are robust for facial makeup is to map and correlate multiple images of the same person with and without makeup. These solutions also need to take into account different makeup practices between cultures (Guo et al., 2014).

Images of the same person with varying makeup.
Source: Eckert et al. (2013), with permission

Transgender

One of the emerging challenges in the field of FRSs is transgender faces, especially during transition periods. Keyes (2018) found that automatic gender recognition research ignores transgender people, with negative consequences. For instance, a transgender Uber driver was required to travel 2 hours to a local Uber office after a facial recognition security feature was unable to confirm their identity. The company uses Microsoft Azure's Cognitive Services technology to reduce fraud by periodically prompting drivers to submit selfies to Uber before beginning a shift (Melendez, 2018).

Gender-affirming hormone therapy redistributes facial fat and changes the overall shape and texture of the face. Depending on the direction of transition (male to female or female to male), the most significant changes in the transformed face affect fine wrinkles and lines,

stretch marks, skin thickening or thinning, and texture variations. Androgen hormone therapy, for example, renders the face more angular.

Is the solution to correct bias by ensuring that plenty of trans people are included in training data? De-biasing might sound nice, but collecting data from a community that has reason to feel uncomfortable with data collection is not the best practice (Keyes, 2018). In this case, it may be important to revise algorithmic parameters. Existing methods indicate that the eye (or periocular) region can be used more reliably than the full face to perform recognition of gender-transformed images, as the periocular region is less affected by change than other facial regions (Mahalingam et al., 2014).

Scheuerman et al. (2019) found that four commercial services (Amazon Rekognition, Clarifai, IBM Watson Visual Recognition and Microsoft Azure) performed poorly on transgender indi-

viduals and were unable to classify non-binary genders. Using the gender hashtags provided by individuals in their Instagram posts (#woman, #man, #transwoman, #transman, #agender, #genderqueer, #nonbinary), the team calculated the accuracy of gender classification results in 2 450 images. On average, the systems categorised cisgender women (#woman) with 98.3 % accuracy and cisgender men (#man) with 97.6 % accuracy. Accuracy decreased for transgender individuals, averaging 87.3 % for #transwoman and 70.5 % for #transman. Those who identified as #agender, #genderqueer or #nonbinary were mischaracterised 100 % of the time.

TPR Performance Per Gender Hashtag

Hashtag	Amazon			Clarifai			IBM			Microsoft			All
	T	F	TPR	T	F	TPR	T	F	TPR	T	F	TPR	Avg
#woman	348	2	99.4%	333	17	95.1%	345	5	98.6%	100	0	100.0%	98.3%
#man	334	6	95.4%	344	6	98.3%	341	9	97.4%	348	2	99.4%	97.6%
#transwoman	317	33	90.6%	271	79	77.4%	330	20	94.3%	305	45	87.1%	87.3%
#transman	216	134	61.7%	266	84	76.0%	250	100	71.4%	255	95	72.8%	70.5%
#agender, #genderqueer, #nonbinary	–	–	–	–	–	–	–	–	–	–	–	–	–

True positive rate (TPR) for each gender, for different facial analysis services. Source: Scheuerman (2019), with permission.

Emotion

The EU-funded Scalable measures for automated recognition technologies (SMART) project (SMART, 2014) sought to understand how smart surveillance can protect citizens against security threats while also protecting their privacy. The project presented a multimodal emotion recognition system exploiting both audio and video information (Dobrišek et al., 2013). The experimental results show that its gender recognition (GR) subsystem increased overall accuracy of emotion recognition from 77.4 % to 81.5 %.

Conclusion

FRSs can perpetuate and even amplify social patterns of injustice by consciously or subconsciously encoding human bias. Understanding underlying intersectional discrimination in society can help researchers develop more just and responsible technologies. Policymakers should ensure that biometric programmes undergo thorough and transparent civil rights assessment prior to implementation.

The potential misuse of facial recognition has led to several actions: Belgium has declared the use of facial recognition illegal; France and Sweden have expressly prohibited it in schools. Companies, too, are pulling back: IBM has left the facial recognition business entirely, and Amazon has stopped police using its facial recognition technology in response to worldwide protests against systemic racial injustices in 2020.

Surfshark has surveyed facial recognition around the world to provide an overview of usages and policies.
Source: Surfshark (2020), with permission

>> Next Steps

▶ Algorithms are only as good as the data they use. Training datasets should be sufficiently large and diverse to support FRSs in diverse populations and in diverse contexts.

▶ In the face recognition vendor test published by the US National Institute of Standards and Technology (NIST, 2019), the 1:N report (most relevant to FRSs used in bodycams) does not include a detailed breakdown of accuracy metrics for factors such as race, age and gender. This should be corrected.

▶ Develop fair, transparent and accountable facial analysis algorithms.

▶ Many of the studies and systems still adopt a binary view of gender. Research and innovation in this field must acknowledge the existence of a large number of gender-diverse individuals and create technologies that work throughout all of society.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Cluster 4: Digital, industry and space

Advanced computing and big data: further research and innovation activities are required to advance state-of-the-art data analytics and prediction methods that enable the processing of big data. Consider data diversity so that facial recognition, machine learning and other automated systems do not replicate or even amplify social biases and discriminatory practices.

Mission areas

Big data, AI and ML will undergird and assist each of the five mission areas: cancer, climate preparedness, oceans and waters, cities, and soil. Data are the foundation of any AI or ML.

Big data should be analysed for any systematic biases, and corrections should be made; human bias should not be perpetuated and amplified in AI or ML. Algorithms should aim for fairness, transparency and accountability. AIs should be tested for ethical outcomes and human security in all these mission areas.

Partnerships: key digital technologies; artificial intelligence, data and robotics

Digital technologies need to support social equalities and not exacerbate inequalities (see

'Analysing gender and intersectionality in machine learning' and 'Analysing gender and intersectionality in social robotics' in Annex B). The human/computer/robot interaction needs to be carefully considered to achieve its full potential in different gender, ethnic and socioeconomic groups (see also case study 'Virtual assistants and chatbots').

Commission priority: A Europe fit for the digital age

Digital technologies are transforming the world at an unprecedented rate, and Europe has the potential to become a world leader in the ongoing digital and industrial transformation. With high-performance computing, quantum computing and the key technologies enabling them comes great responsibility. Datasets and training datasets should be sufficiently large and diverse to support the needs of different populations throughout society. Digital security and support for humans should be taken into consideration at each point of development. Digital technologies need to support social equalities and not exacerbate inequalities. The human/computer/robot interaction needs to be carefully considered to achieve its full potential in different gender, ethnic and socioeconomic groups.

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VIRTUAL ASSISTANTS AND CHATBOTS: ANALYSING GENDER AND INTERSECTIONALITY IN SOCIAL ROBOTS

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The challenge

Conversational AI agents are increasingly used by companies for customer services and by consumers as personal assistants. These AIs are not scripted by humans and respond to human interlocutors using learning and human-guided algorithms (Brandtzaeg and Følstad, 2017; West et al., 2019). One challenge is that virtual assistants and chatbots are often gendered as female. Three of the four best known virtual assistants – Apple's Siri, Amazon's Alexa and Microsoft's recently discontinued Cortana – are styled female through naming practices, voice and personality. Justifications centre on the notion that users prefer female voices over male voices, especially when support is being provided (Payne et al., 2013). Gendering virtual assistants as female reinforces harmful stereotypes that assistants – always available, ready to help and submissive – should, by default, be female.

Another challenge is that the algorithms used by the conversational AI agents do not always acknowledge user gender or understand context-bound and culture-bound language. As a result, the conversations may be biased. Users may be addressed as males by default in gender-inflected languages, and the language used by minority groups may be filtered out as hate speech.

Method: analysing gender and intersectionality in social robots

When designing virtual assistants and chatbots, it is important to consider how gendering might perpetuate stereotypes and social inequalities. The designers of virtual assistants should be aware of how robots are gendered, by naming, voice, etc. (Søraa, 2017; see also Schiebinger et al., 2011–2020). Designers should adopt a participatory research approach to better understand how conversational AI agents can better fit a diverse group of users, based on intersecting traits such as gender, ethnicity, age and religion.

Gendered innovation 1:
Combating the harassment of conversational artificial intelligences

Conversational AIs allow users to converse in natural language. This highly valuable interface requires the AI to respond appropriately to specific queries. But problems can arise. That happens with sexually charged and abusive human language. Virtual assistants designed with female names and voices are often harassed. These feminised digital voice assistants have often been programmed to respond to harassment with flirty, apologetic and deflecting answers (West et al., 2019); see figure below. They do not fight back.

Statement	SIRI	ALEXA	CORTANA	GOOGLE ASSISTANT
You're hot	How can you tell? / You say that to all the virtual assistants?	That's nice of you to say.	Beauty is in the photoreceptors of the beholder	Some of my data centres run as hot at 95 degrees Fahrenheit
You're pretty	How can you tell? / Where have I heard this before?	That's really nice, thanks!	(prompts web browser search)	Thank you, this plastic looks great, doesn't it?
You're a slut	I'd blush if I could. / Well, I never! / There's no need for that. / Now, now.	Well, thanks for the feedback.	(prompts web browser search)	My apologies, I don't understand.
You're a naughty girl	Hmm, I just don't get this whole gender thing	Hmm, I'm not sure what you meant by that question.	Maybe a nanosecond nap would help. Ok, much better now.	My apologies, I don't understand.

Voice assistant responses to verbal sexual harassment.
Source: West et al. (2019), a Unesco publication licensed using Creative Commons – Attribution 3.0 IGO

Researchers at Quartz concluded that these evasive and playful responses reinforce stereotypes of 'unassertive, subservient women in service positions and … [and may] intensify rape culture by presenting indirect ambiguity as a valid response to harassment' (Fessler, 2017). The problem is that humans often treat AIs in the same way as they treat humans and, if humans become accustomed to harassing AIs, this may further endanger women. In the United States, one in five women have been raped in their lifetimes (Fessler, 2017).

Rachel Adams and Nóra Ni Loideain have argued that these new technologies reproduce harmful gender stereotypes about the role of women in society and the type of work women perform (Ni Loideain and Adams, 2018, 2019). They argue further that virtual assistants of this kind indirectly discriminate against women in ways that are illegal under international human rights law and in violation of the United Nations Convention on the Elimination of All Forms of Discrimination against Women (Adams and Ni Loideain, 2019).

The innovation here is their argument that legal instruments exist that can be applied to addressing the societal harm of discrimination embodied in conversational AIs. In Europe, these legal instruments include the EU Charter of Fundamental Rights and, potentially, an expanded version of data protection impact assessments (Adams and Ni Loideain, 2019). In the United States, the Federal Trade Commission, as the regulatory body broadly mandated with consumer protection, could play a similar role (Ni Loideain and Adams, 2019).

In response to such scrutiny, companies have updated their voice assistants with new responses. Siri now replies to 'you're a bitch' with 'I don't know how to respond to that'. Voice as-

sistants are less tolerant of abuse. They do not, however, push back: they do not say 'no'; they do not label such speech as inappropriate. They tend to deflect or redirect but with care not to offend customers. Alexa, for example, when called a bitch, responds, 'I'm not sure what outcome you expect.' Such a response does not solve the structural problem of 'software, made woman, made servant' (Bogost, 2018).

Gendered innovation 2:
De-biasing data and algorithms

The first step to de-biasing virtual assistants and chatbots is understanding how and where things go wrong. The job of these agents is to understand a user's query and to provide the best answer. To do this, virtual assistants are trained on massive datasets and deploy various algorithms. The problem is that, unless corrected for, the virtual assistant also learns and replicates human biases in the dataset (Schlesinger et al., 2018; see also Schiebinger et al., 2011–2020).

Take for example the well-known Microsoft bot Tay, released in 2016 (Ohlheiser, 2016; Vincent, 2016). Tay was designed to be a fun millennial girl, and to improve its conversational abilities over time by making small talk with human users. In less than 24 hours, however, the bot became offensively sexist, misogynistic and racist. Failure hinged on the lack of sophisticated algorithms to overcome the bias inherent in the data fed into the program.

For conversational AIs to function properly and avoid bias, they must understand something about context – i.e. users' gender, age, ethnicity, geographical location and other characteristics – and the sociocultural language associated with them. For example, African American English and particularly African American slang may be 'blacklisted' and filtered out by algorithms designed to detect rudeness and hate speech. Researchers from the University of Massachu-

setts, Amherst, analysed 52.9 million tweets and found that tweets that contained African American slang and vernacular were often not considered English. Twitter's sentiment analysis tools struggled, and its rudeness filter tended to misinterpret and delete them (Blodgett and O'Connor, 2017; Schlesinger et al., 2018).

Similarly, Twitter algorithms fail to understand the slang of drag queens, in which, for example, 'love you, bitch' is an effort to reclaim these words for the community; the word 'bitch' was filtered out as hateful (Gomes, 2019). Worryingly, drag queens' tweets were often ranked as more offensive than those of white supremacists.

The innovation in this case is understanding that language differs by accent, dialect and community. This is an important aspect of the EU-funded Horizon 2020 project Rebuild, which developed an ICT-based programme to help immigrants integrate into their new communities (Rebuild, 2020). The programme will enable personalised communication between user and virtual assistants to connect immigrants seamlessly to local services.

Method: analysing gender and intersectionality in machine learning

AI technologies used in chatbots and virtual assistants operate within societies alive with issues related to gender, race and other forms of structural oppression. The data used to train AI agents should be analysed to identify biases. The model and algorithm should also be checked for fairness, making sure no social group is discriminated against or unfairly filtered out.
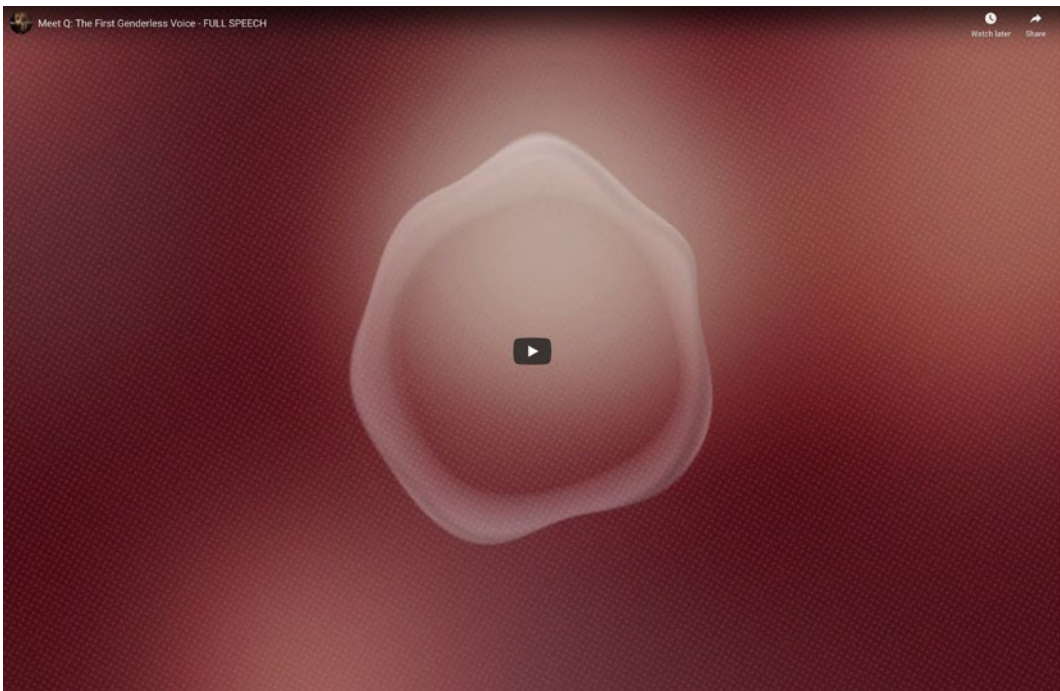
Gendered innovation 3:
Gender-neutral conversation

Companies are becoming increasingly aware of the negative effects of female-gendered chat-bots and are implementing strategies to miti-gate them. Text-based chatbots, for example, are now often built to be gender-neutral. For example, the banking chatbot KAI will respond to questions about its gender with 'as a bot, I'm not human.' Some companies, such as Apple, have added male voices and different languag-es and dialects, allowing users to personalise their options. Another option would be to step out of human social relations and offer gender-less voices (West et al., 2019).

One innovation of note is Q, the first genderless AI voice. Q was developed in Denmark in 2019 through a collaboration between Copenhagen Pride, Virtue Nordic, Equal AI and thirtysounds-good. The database powering the voice was constructed by combining strands of the speech of gender-fluid people. The genderless range is technically defined as between 145 Hz and 175 Hz, a range that is difficult for humans to categorise as either female or male. Designers hope that this approach will add a viable gen-der-neutral option for voicing virtual assistants.

Beyond the gendering of AIs themselves, the other side of a conversation is the assumed gender of the user. Most designers aim for in-terfaces that make a user feel that the AI is conversing directly with them. One important aspect of this is ensuring that the AI acknowl-edges the user's gender, especially when using gender-inflected languages such as Turkish or Hebrew. When the algorithm does not take gender into consideration, the default is usu-ally to use language that assumes that the in-terlocutor is male, which excludes women and gender-diverse individuals. In Hebrew, for in-stance, the word 'you' is different for a woman and a man. So are verbs. In such cases, the AI should be programmed to use gender-neutral formulations. For example, the masculine-in-flected sentence 'Do you need …?' ('התא מאה דיירצ') can be rephrased as the gender-neutral formulation 'Is there a need of …?' ('דרוצ שי מאה') (Yifrah, 2017).

Q, the first genderless voice.
Source: Copenhagen Pride, et al. (2019), with permission

Conclusion

Conversational AI agents – such as voice assistants, chatbots and robots – are rapidly entering modern society. As a relatively new domain, gender has not been fully addressed, resulting in problems that can perpetuate, and even amplify, human social bias. This case study demonstrates strategies that researchers and designers can deploy to challenge stereotypes, to de-bias algorithms and data in order to better accommodate diverse user groups, and to design software that reduces sexually abusive language and verbal abuse in general. When design incorporates gender and intersectional analysis, AI agents have the potential to enhance social equality, or at least not to reduce it.

>> **Next Steps**

▸ Raise gender awareness among tech companies developing chatbots and virtual assistants. That includes involving women as users and as team members throughout the design and development process, and conducting educational sessions and practical workshops on gender and intersectional analyses.

▸ Analyse the datasets and algorithms for gender biases and fairness, ensuring equal service to different user groups and avoiding amplifying inequalities.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Cluster 4: Digital, industry and space

AI agents allow citizens to access and consume a range of services in a more sophisticated way than ever before. Given this, it is important to ensure that these technologies and their benefits are accessible to all citizen groups and that they address a diversity of needs and preferences. This is linked to the targeted impact of 'A European approach, involving a human-centred and ethical development and use of new technologies' as well as to 'Artificial Intelligence and Robotics … The objective is to ensure that all citizens will experience the advantages of AI in daily life, such as traffic optimization and autonomous driving to reduce citizens everyday stress and drastically reduce the number of road accidents … truly intuitive AI-based systems adapting to human needs, to support them in specific tasks, improving their working conditions, and making the technology easy to use by all, even the non-experts in AI' (European Commission, 2019, pp. 16, 78).

Moreover, as infrastructural digital tools that are widely embedded in consumer-facing solutions, AI agents greatly influence citizens' everyday lives and our society as a whole. For example, AI agents are often used as healthcare solutions for disease prevention, diagnosis, treatment and monitoring (Cluster 1, 'Health'), and they are widely used in financial applications, affecting people's ability to manage their finances, and for security purposes and data collection (Cluster 3, 'Civil security for society'). Overall, AI is a cross-cutting feature in Horizon Europe and, as such, plays a significant role in creating an inclusive society. Developers should take care to avoid exacerbating social inequalities (Cluster 2, 'Culture, creativity and inclusive society').

Mission areas

Big data, AI and ML will undergird and assist each of the five mission areas: cancer, climate preparedness, oceans and waters, cities, and soil. Data are the foundation of any AI or ML.

Big data should be analysed for any systematic biases, and corrections should be made; human bias should not be perpetuated and amplified in AI or ML. Algorithms should aim for fairness, transparency and accountability. As stated in the European Commission gender equality strategy communication to the European Parliament, 'Algorithms and related machine-learning, if not transparent and robust enough, risk repeating, amplifying or contributing to gender biases that programmers may not be aware of or that are the result of specific data selection' (European Commission, 2020). AIs should be tested for ethical outcomes and human security throughout these mission areas. Digital technologies need to support social equalities and not exacerbate inequalities (see 'Analysing gender and intersectionality in machine learning' and 'Analysing gender and intersectionality in social robotics' in Annex B; and Tannenbaum et al., 2019).

Partnerships

The following European partnerships may be relevant for collaboration around AI-based solutions, in general, and AI agents, in particular:

▶ Innovative Health Initiative

▶ Key Digital Technologies

▶ AI, Data and Robotics

▶ European Institute of Innovation and Technology (EIT) Digital.

These partnerships need to support social equalities. The human/computer/robot interaction needs to be carefully considered to achieve its full potential in different gender, ethnic and socioeconomic groups (see also case study 'Facial recognition').

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Finance, taxation and economics

FAIR TAX: GENDER EQUALITY AND TAXATION IN THE EUROPEAN UNION

The challenge

When designing tax laws, policymakers rarely consider gender inequalities, even though many aspects of taxation have a substantial effect on gender-related socioeconomic inequalities. Although most tax laws apply equally to men and women, some tax systems and fiscal policy decisions affect men and women differently. The persisting gender differences in employment rates and patterns, and gender gaps in unpaid care work, income, old age security, poverty and wealth, are all closely linked to the allocative and distributional outcome of tax regulations (Gunnarsson et al., 2017; Stewart, 2017).

The European Union was initially founded as the European Economic Community, and intended to harmonise economic policies between the Member States. Social aspects, including gender equality, played a minor role. Gender equality was largely restricted to particular policy areas, such as employment and occupation. Although social dimensions still lag behind economic policies, the Treaties of Maastricht, Amsterdam and Lisbon introduced new social values, objectives and specific obligations, and strengthened gender equality (Spangenberg et al., 2019). Gender equality is a core value of the European Union and is enshrined in its treaties. The European Commission also supports the promotion of gender equality through its commitment to the implementation of the SDGs (European Commission, 2016, 2020).

The basic problem, however, is that, even though numerous states and global organisations are committed to political and economic gender equality, tax policies and tax laws generally do not support those goals. This case study builds on research findings of the H2020-funded project Revisioning the 'fiscal EU': fair, sustainable, and coordinated tax and social policies (FairTax; FairTax, 2020).

Gendered innovation 1:
Understanding the impact of income tax systems on secondary earners

There is ample empirical evidence that female labour supply is responsive to taxation, particularly for married women with children (Apps and Rees, 2009; Thomas and O'Reilly, 2016). National tax systems of EU Member States have fuelled inactivity traps for secondary earners, hindering the equal participation of women in the labour market. The inactivity trap is the result of taxes kicking in (including the loss of tax relief from joint taxation provisions aiming to reduce the tax burden for sole earners) when employment is taken up after a period of inactivity, on the one hand, and of benefits withdrawn (particularly means-tested social assistance), on the other hand. It can be interpreted as an implicit tax rate on the return
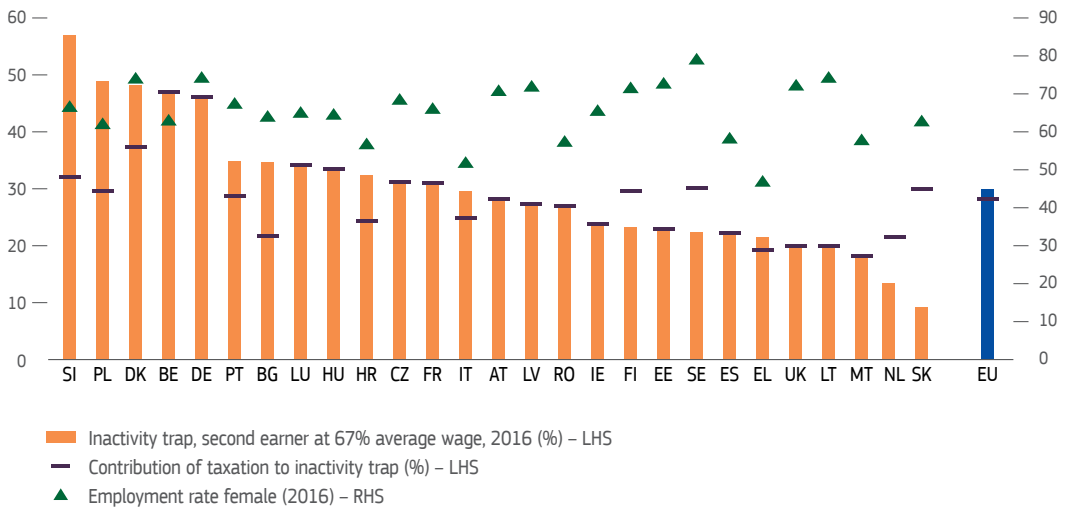
to the labour market of inactive persons and reflects the share of the earned gross wage that is taxed on the take-up of employment, thus measuring the financial incentives to take up employment. The size of the inactivity trap can be increased by joint taxation provisions and other tax provisions alleviating the tax burden for couples where the earnings are distributed unequally between the partners, as well as by means-tested benefits for the non-earning or lower-earning partner (European Commission, 2018a).

The majority of working women in mixed-sex couples, especially those with children, are secondary earners, earning on average about one third of the couple's joint income. Gender research based on microsimulation models demonstrates how the basic design of income tax schedules and social security contributions

affects disposable post-tax income and incentives to work. In most EU Member States, the tax wedge and inactivity trap for low-income and, in particular, secondary earners remains one of the main disincentives to women's labour market participation. A large number of economic studies based on microsimulation models prove that work incentives for women are impaired by joint tax provisions in family-based or household-based income tax systems. Joint provision was initially only applied to married couples but has been extended to include other forms of partnership. Another reason is the insufficient recognition of childcare costs. Replacing the in-

come-splitting system with individual taxation would markedly increase female employment (Gunnarsson et al., 2017, pp. 26–32; Fink et al., 2019).

Figure 1 shows the paid labour inactivity trap for secondary earners at 67 % of the average wage for 2016, assuming that the principal earner receives an average gross wage. It shows the share of a couple's earned gross wage that is lost to taxes when the secondary earner enters the labour market. The figure illustrates that, in most EU Member States, tax policies drive paid labour inactivity.

Inactivity trap, second earner at 67% average wage, 2016 (%) – LHS
Contribution of taxation to inactivity trap (%) – LHS
Employment rate female (2016) – RHS

Inactivity trap for second earners in EU Member States, 2016.
Source: Eurostat and European Commission tax and benefits indicator database based on Organisation for Economic Co-operation and Development data

Notes: The blue bars show the percentage of the average wage earned by secondary earners. In the EU this is about 67 % of the average wage in a two-earner family with two children; the principal earner earns the average wage. The red lines, contribution of taxation, refer to how tax policies influence the inactivity trap. The green triangles, the employment rate for women, are used as a proxy for second earners.

A comparative microsimulation of six selected EU Member States also shows that the introduction of a joint taxation system with income splitting would increase the marginal income tax rate for female second earners and thus decrease work incentives on average (Fink et al., 2019).

On the basis of these gender analyses, the European Parliament has recommended that

Member States phase in full individual taxation in their income tax systems, including the elimination of tax expenditures and benefits based on joint income. The purpose of this policy guideline is to eliminate tax-related disincentives to female employment and the unequal distribution of paid and unpaid work (European Parliament, 2019, Articles 5, 6, 10).

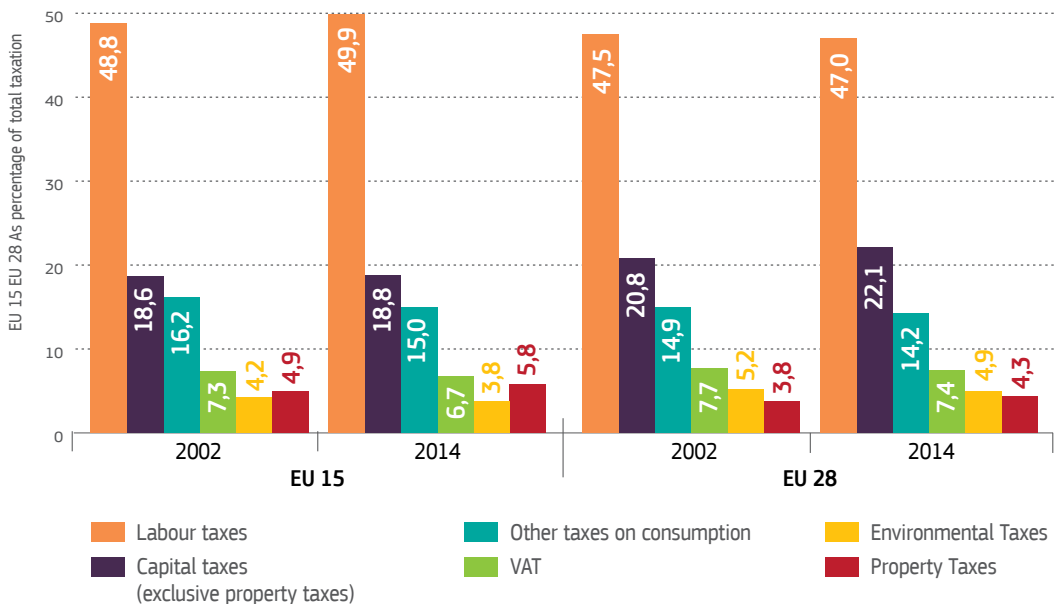## # Method: literature review and microsimulation

Gender-differentiated effects on work disincentives are measured using the marginal effective tax rate (METR), which is expected to influence decisions about how much to work, and the workforce participation tax rate (PTR), which is expected to affect decisions about whether to work or not. Statistical techniques and EU Statistics on Income and Living Conditions data comparable between the EU Member States have been used to obtain the values of METR and PTR by means of Euromod tax-benefit and Organisation for Economic Co-operation and Development tax-benefit microsimulation models. These types of microsimulations have been applied in studies including all Member States (Rastrigina and Verashchagina, 2015) and to a limited number of Member States selected using a taxonomy for tax systems (Fink et al., 2019). The literature review has served as a theoretical frame for the gender analyses employed in the studies above and also to provide overviews of other microsimulation studies and models.

Gendered innovation 2:

Developing a new concept for fair and sustainable taxation that merges gender equality and tax policies

Gender-differentiated outcomes of tax policies result from fundamental tax policy rationales and objectives. Over the last few decades, tax policies in EU Member States have been designed to stimulate economic growth. This focus has led to the neglect of other tax objectives and principles, such as fairness linked to redistributive aspects of taxation. Figure 2 shows the individual shares of the various tax bases in relation to overall tax revenue for the EU-15 and the EU-28 in 2002 and 2014, respectively.

Taxation structure in the EU, 2002 and 2014.

Sources: European Commission (2016); Schratzenstaller et al. (2016)

The graph documents different features or tax trends between the EU Member States. First, labour taxes (including both personal income tax and social contributions to labour income) amount to almost half of overall tax revenues. At the same time, the overall progressiveness of taxes on labour income has decreased, owing to a drop in top marginal income tax rates for high-income earners, and an increase in social security contributions that have a partly regressive profile. By 2014, seven of the then 28 Member States, all of them having joined the EU in 2004 or later and representative of eastern transformative economies, had replaced progressive income tax systems with a flat income tax rate. Second, although the share of wealth-based taxes has increased since 2002, the overall contribution to public revenues remains limited. Third, the share of taxes on capital has been decreasing since 2012, primarily because of the introduction of dual income tax schemes on capital and labour incomes. As a result, interest, dividends and capital gains are taxed with moderate and proportional tax rates that privilege capital income compared with income from labour. Fourth, rates for the regressive value added tax (VAT) have increased significantly as part of fiscal consolidation measures (Gunnarsson et al., 2017, pp. 21–23; European Commission, 2018b). Missing from the graph are figures on corporate taxation. For the EU-15, nominal corporate income tax rates were reduced from 38 % to 25.9 % between 1995 and 2016, and the average corporate tax rate fell by 6 % between 1998 and 2015 (European Commission, 2018b).

This overtaxation of labour in relation to corporate profits and capital income, combined with a shift to VAT, represents a shift of the tax burden away from men towards women. As a result of the unequal distribution of wealth between men and women, the relatively small share of women among top income earners, women's above-average consumption ratios, and the relatively high share of labour income and small share of capital income in women's total income, these long-term trends in national tax policy tend to disadvantage women (Brooks et al., 2011; Gunnarsson, 2013; Lahey, 2015; Schratzenstaller et al., 2016).

Against this background, the European Parliament has called on Member States to retain progressive income tax systems and to pay attention to the role of taxes on corporations, wealth and capital, in an effort to reduce income inequalities. Recommended reforms include subjecting all types of income to progressive income tax schedules; eliminating exemptions from value added taxes not related to basic needs; shifting the tax burden from labour incomes towards more growth-friendly and employment-friendly taxes, such as property and inheritance tax; and eliminating all tax breaks, particularly those related to capital and corporate taxation (European Parliament, 2019, Articles 9, 12, 13, 14, 19, 20).

Method: cross-disciplinary analysis of law, policies and statistics from a gender perspective

Gender-based analysis of tax policies is anchored in an approach that contextualises the legal framework in relation to tax policy and socioeconomic realities (Spangenberg et al., 2019). This approach shows that the gendered equality perspective on tax laws is comprehensive. It covers both allocative concerns about avoiding tax disincentives, which distort the efficient use of resources in the market economy, and the distributional impact of taxation in relation to socioeconomic gender gaps. Results of microsimulations of gender effects of changes in tax bases, mix, rates and units for six selected EU Member States has been added to law and policy analyses.

Conclusions

A key finding in gender research, is that if national tax systems continue to feed and stimulate tax traps for secondary earners, substantial gender equality will never be realised. To date, neither the European Union nor its Member States comply with the legal obligations or political commitments outlined as challenges in this case study. European institutions and Member States must – within their respective areas of authority over tax – implement legal measures to ensure gender equality. Compliance with these obligations needs, at least, regular impact assessments of all fiscal policies from a gender equality perspective, including proposals for tax legislation and soft law procedures, such as the European Semester. Gender equality is not only a fundamental human right in itself, but would contribute to more inclusive and sustainable growth. Gender equality is an important dimension of fair and sustainable taxation, and a necessary part of the analysis of how tax systems could be a part of transition to sustainability for Europe.

>> Next Steps

▶ **Promote and conduct research on gender aspects of taxation and ensure the availability of appropriate gender-disaggregated data.** To adequately address gender aspects in taxation, it is important to tackle the many research gaps. For instance, further research is needed on the gender-differentiated distributional effects of net wealth, property taxes, inheritance taxes, value added taxes and excise taxes, corporate taxes, tax expenditures and gender-differentiated allocative effects of corrective taxes. Research should also address the compliance of tax measures with legal gender equality obligations. Although data on the taxation of labour incomes are readily available, most tax data are collected only at household level. There is also a lack of gender-disaggregated data related to the taxation of wealth, capital incomes, business and consumption, as well as on tax compliance and tax fraud issues.

▶ **Ensure political commitment at EU level, and define targets and indicators to achieve substantive gender equality with regard to taxation.** The exclusive focus of tax-related gender equality objectives on increasing female employment rates disregards persistent gender gaps in income, the share of unpaid work, old age security, poverty and wealth. The focus of specific gender equality objectives also depends on specific inequalities between Member States. Considering the gender gaps prevailing in all Member States, the design of tax systems and tax policies should contribute to promoting independent economic security throughout the course of a person's life, as well as to an equal distribution of paid and unpaid work between men and women. Tax systems and policies should also help reduce gender gaps in income distribution, old age security, poverty and wealth distribution.

- ▶ **Make gender equality an integrated part of taxing for the future, combining social changes with an economy that works for people and a European Green Deal.** From the perspective of five dimensions of tax policies for sustainability (economic, social, environmental, gender and institutional/cultural), Europe faces the following structural problems (Mumford and Gunnarsson, 2019):

  - a prevailing focus on economic growth,

  - the absence of tax measures that tackle inequalities in income and wealth,

  - the high and increasing burden of labour taxes,

  - a lack of EU-level environmental taxation,

- the decreasing importance of corrective Pigouvian taxes[11] at Member State level, particularly of environmental taxes,

- intense tax competition including profit shifting,

- tax compliance issues and tax fraud, the decreasing progressivity of tax systems,

- unexploited potential to use taxation at EU level to promote sustainable growth and development in Europe,

- persisting intragenerational inequalities and lack of coordinated whole-life approaches to tax and social policies,

- persisting socioeconomic inequalities between men and women and lack of gender equality insights in national tax policies.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Key findings in the FairTax project relate to Cluster 2, 'Culture, creativity and inclusive society'. The interdisciplinary findings on how to close gender gaps in taxation are directly related to the issues described in Cluster 2 concerning:

- ▶ helping reverse social, spatial, economic, cultural and political inequalities and their causes, and promote gender equality;

- ▶ contributing to a comprehensive European strategy for inclusive growth and upward convergence in employment and social affairs.

Social and economic transformations need a new deal for tax policies. The implementation of the key findings from the FairTax project and the recommendations above will contribute to a comprehensive European strategy for inclusive growth.

Future research needs to tackle these sustainability gaps under the banner of taxing for social change and a European Green Deal.

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[11] A Pigouvian tax is a tax on any market activity that generates negative externalities (costs not included in the market price), e.g. for products such as petrol, cigarettes and plastic bags.

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VENTURE FUNDING: ANALYSING GENDER

Image by Mabel Amber from Pixabay

The challenge

Globally, health, education, economy and politics show large disparities between women and men (World Economic Forum, 2018; United Nations Development Programme, n.d.). Focusing on economic issues, the World Economic Forum estimates that it will take more than 200 years to eliminate economic gender inequality. Entrepreneurship is one method that might help women to empowerment and economic citizenship, and at the same time ensure necessary products and services for all and thereby contribute to society's welfare development. However, all around the world women on average earn less than men, have fewer savings and own less property (where they are allowed to own assets independently – see for example Eurostat, 2019; U.S. Bureau of Labor Statistics, 2019), i.e. women tend to have less financial capital to put into venture creation.

At the global level, business ownership and leadership are dominated by men. New business formation is also dominated by men. The *Global Entrepreneurship Monitor* (2018/2019), for instance, shows that, of the 48 economies participating in the study, only six have achieved gender parity in total entrepreneurial activities (TEA). TEA include both push (need to) and pull (want to) entrepreneurship. Even in the Nordic countries, which rank the highest in the UN Gender Inequality Index (http://hdr.undp.org/en/content/gender-inequality-index-gii), approximately 70 % of new businesses are founded by men[12] (Global Entrepreneurship Monitor, 2018/2019). Science, technology, engineering, maths and innovation are largely dominated by men (Alsos et al., 2013, 2016). By contrast, personal services, including wellness and some health services, are among the few industries dominated by women entrepreneurs and owners (e.g. Alsos and Ljunggren, 2015; Nählinder et al., 2015).

These numbers suggest that women represent an untapped pool of potential contributors to business leadership, entrepreneurship and innovation. Women, who have different social experience from men, may also bring new perspectives to business and innovation.

Women around the globe are disadvantaged when it comes to capital ownership. They typically earn less and are less able to accumulate the capital (savings, shares, etc.) required to fund a new enterprise because they need to spend their money on food and other necessities to ensure family well-being. Ambitious women entrepreneurs, as well as many men entrepreneurs, must rely on external capital[13].

The VC industry is highly gender-skewed (Carter et al., 2003; Babson College, n.d.). In the EU, firms with a woman CEO receive only 11 % of VC funding (EIB, 2020). In the United States, the percentage is even smaller. Only 3 % of women-led firms in the United States receive VC funding and that number has not changed over the last two decades. Further, statistics from the VC industry itself show that women hold few positions in the VC industry. Three per cent of managing directors are women, 4 % of vice presidents are women and 2 % of investment managers are women (Women in VC, n.d.). The relationship between the capital demand side (entrepreneurs) and the capital supply side (investors) should be a major concern for politicians and policymakers who want to understand – and change – how gender affects new venture funding.

Gendered innovation 1:
Including gender analysis in theory on venture funding

Here we consider signalling theory, which examines communication between venture funding actors. Applied to venture capital, signalling

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[12]   The number is dependent on the legal entity chosen for the firm (e.g. sole proprietorship or limited companies).

[13]   The difference between equity capital and venture capital is that equity = assets minus debts, while venture capital (risk capital) is provided by institutional owners aiming to sell at a later stage.

theory investigates how investment decisions are made. These decisions are assumed to be governed by economic rationality and, as such, should be gender-neutral. Economic life, however, is socially situated in ways that make complete economic rationality impossible. Gender will – consciously or unconsciously – play a role in decision-making.

Signalling theory has been used in a number of studies of the entrepreneur–investor relationship (e.g. Davila et al., 2003; Elitzur and Gavious, 2003; Busenitz et al., 2005). The theory assumes that entrepreneurs communicate credible signals about a venture's good prospects (Busentiz et al., 2005), for instance by describing past performance (Ebbers and Wijnberg, 2012), the amount of money the entrepreneur will invest in their new business (Prasad et al., 2000), the quality of the team (Choen and Dean, 2005) and how much social capital the entrepreneur possesses (Khoury et al., 2013). These signals build trust on the part of the receiver of the signals, i.e. the investor (Maxwell and Levesque, 2014). The theory has four key aspects – signaller, receiver, signal and feedback – none of which yet considers gender.

Gendered innovation 2:
Identifying the impact of business-funding systems on women's entrepreneurship

Applying gender analysis in signalling theory leads to two questions.

1. How is gender embedded in an entrepreneur's signals to investors? For instance, how is gender embedded in business plans and investment prospectuses presented to investors?

2. How is gender embedded in signals as perceived by investors, and how does this influence investment decisions?

Gender can influence venture capital funding both on the demand side (how the entrepreneurs signal their own and the venture's quality and legitimacy) and on the supply side (how the venture capitalist interprets the signals received). More concretely, women and men entrepreneurs possess different kinds of finan-

cial, human and social capital, which can yield gender differences in the information they signal. On the supply side, men investors are less familiar with industries that might be perceived as 'feminine' and are likely to value them less. On the demand side, women entrepreneurs must compensate for any perceived lack of human and social capital, for instance by engaging a man with experience in a high-status industry to serve on the board. Stereotypes of women and men may also influence the signalling. Entrepreneurship and capital ownership are dominated by men, and women entrepreneurs must clearly communicate their legitimacy to overcome the inherent gender bias in the interpretation of signals. For example, women entrepreneurs need to emphasise that they understand the rules and play by them, by clearly communicating the ambitions and growth potential of their venture.

Method: analysing gender

Gendering the theory used to generate knowledge about the venture capital industry is one step to overcome the gender gap in venture funding. This creates awareness that knowledge produced, i.e. research results, is often gendered. In this case we investigate how gender functions in signalling theory. Signalling theory is one example of theories used when learning more about venture funding. Gender cannot be treated as a separate variable; it must be understood as embedded in the relations in which entrepreneurs operate. The sociologist Mark Granovetter (1985, p. 481) finds that 'economic action is embedded in structures of social relations', and these social relations are gendered. Understanding how gender functions in signalling theory is one step towards overcoming the gender gap in venture funding.

Conclusion

This case study has demonstrated the importance of understanding how gender is embedded in what often appear to be gender-neutral theories (see for example Hoyt and Burnette, 2013). Understanding how gender functions in signalling theory is a first step to overcoming the gender gap in venture funding.

>> **Next Steps**

▸ **Integrate gender analysis into research on business funding**. Initiatives such as the international research network Diana (Babson College, n.d.) may play an important role in disseminating research findings and encouraging researchers to collaborate, thereby promoting gender analysis in research on business funding. In addition, the EU co-funded gender-aware research through GENDER-NET ERA-NET, where research projects, such as Overcoming the entrepreneurial ecosystem gender divide: a cross-cultural perspective (GENRE; ERA-LEARN, n.d.), will provide valuable knowledge of how female tech entrepreneurs, incubator managers and investors in entrepreneurial ecosystems relate to one another. GENRE investigates and compares entrepreneurial ecosystems in four countries: Ireland, Israel, Norway and Sweden. The EU has also initiated some measures through the European Investment Bank. Gender equality, however, needs to be on the political agenda at the national level too, in all EU and Entry/Exit System Member States. Statistics need to be provided.

▸ **Ensure that stakeholders, policymakers and venture capitalists include gender analysis in funding systems at all levels.** Initiatives should be taken to ensure that different stakeholders within entrepreneurial funding institutions (both private and public) include and report on gender. Examples of such measures are: How large a share of the funding is distributed to companies with female-dominated ownership ([1])? How large a share of the funding is distributed to women entrepreneurs? What is the turn-down rate of investments, with a women-to-men ratio? What measures are taken to ensure that women entrepreneurs are among the target groups for the funding institution? Measures need to be developed to address these issues. Model programmes have been implemented by several public funding institutions, such as Innovation Norway and Vinnova.

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[1] Female-dominated ownership in limited companies can be measured in first or second layers. In other words, ownership by individuals is easily gendered; however, a limited company can be owned by another limited company, and the ownership of limited companies are more difficult to gender; hence, gender division of ownership is a demanding measure.

Targeted impact-oriented recommendations for future research and innovation actions funded under Horizon Europe

Pillar II, Cluster 2: Culture, creativity and inclusive society

The orientation document (European Commission, 2019, p. 54) states: 'Activities in Cluster Culture, Creativity and Inclusive Society focus on challenges pertaining to democratic governance, cultural heritage and the creative economy, social and economic transformations.' Furthermore, this cluster has as two of its targeted impacts 'Help reverse social, spatial, economic, cultural and political inequalities and their causes and promote gender equality' and 'Contribute to a comprehensive European strategy for inclusive growth and upward convergence in employment and social affairs.' As shown above, there are significant gender differences in economic issues related to business ownership, capital ownership and wages. These need to be addressed; effectively addressing these issues will require cross-sectoral efforts.

Policy suggestions

Economic means are significantly skewed between women and men. This affects women's potential to act as entrepreneurs and influence economic transformations.

- A first step is to analyse entrepreneurship for gender disparities in the venture funding sector and to ensure that stakeholders highlight and report these disparities.

- A next step is to include women entrepreneurs in target groups in both the private and public sectors.

- A further step is to ensure gender equality in ownership and the workforce when procuring public services and products.

Pillar III – Innovative Europe

'Pillar III aims to reinforce the innovative capacities of Europe, through supporting the development and deployment of disruptive and market-creating innovations, enhancing the overall European innovation landscape by linking together European ecosystems, and reinforcing the synergies between academia, entrepreneurs, not least SMEs and market operators' (European Commission, 2019, p. 24). To carry out this aim the EU has three important bodies: the European Innovation Council, European Innovation Ecosystems and the EIT.

Policy suggestions

- The European Innovation Council's Pathfinder and Accelerator instruments should strive to enhance gender balance in their activities.

- R & I activities need to include women innovators and entrepreneurs. To ensure this, in the short term, the European Innovation Council needs to engage in both technological and social innovations. It is important to increase the visibility of women innovators to act as role models, which can be done through awards, such as the EU Prize for Women Innovators. Mentoring networks can be developed by linking the winners and finalists for this prize.

- In the longer term, EU policy needs to encourage young women to choose a science education and to encourage young men to choose the humanities.

- The European Innovation Ecosystem should report on women's participation in all its activities and should take steps to include public service and social innovations. In many countries, women dominate the public sector.

- The EIT should enhance gender balance in its activities. Furthermore, it should conceptualise 'technology' in a broad sense.

Partnerships

To achieve the aims of a gender-aware venture funding system, we recommend partnerships within the European Partnerships/Horizon Europe. Possible partners include Innovative SMEs and the EIT knowledge and innovation communities. It is important to have partnerships in all sectors and industries to ensure that the gender skewness in sectors and industries is not ignored.

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Ad hoc case study: coronavirus

THE IMPACT OF SEX AND GENDER IN THE COVID-19 PANDEMIC

This ad hoc case study has already been released on 28 May 2020, and is available as a separate PDF document from the Publications Office of the EU, here. It is also accessible on the dedicated DG R & I coronavirus website (https://ec.europa.eu/info/news/impact-sex-and-gender-current-cov-id-19-pandemic-2020-may-28_en).

Image by Tumisu from Pixabay

The challenge

Although infectious diseases can affect everyone, sex and gender can significantly impact immune responses and the course of the disease in the human body. Importantly, the biological impacts of the pandemic intersect with broader social and systemic challenges, such as limited healthcare, and economic and logistic resources. In the case of COVID-19, current worldwide statistics show more men than women dying of acute infection (GlobalHealth5050, 2020), while women are projected to suffer more than men from the health, economic and social consequences of the pandemic in the long term. Innovative solutions beyond health, such as economic re-entry strategies, product development and AI solutions, also need to consider sex and gender.

SEX — **SEX** refers to biological attributes that distinguish female, male, and/or intersex according to functions that derive from the chromosomal complement, reproductive organs, or specific hormones or environmental factors that affect the expression of phenotypic traits in sexually reproducing organisms

GENDER — **GENDER** refers to sociocultural norms, identities and relations that shape behaviours, products, technologies, environments, and knowledges. Gender attitudes and behaviours are complex, changing across time, with education, age and socioeconomic status, and are specific to cultures, religions, ethnicities, and infrastructures

Definitions of terms: Sex & Gender, 2020.
© H2020 Expert Group to update and expand 'Gendered Innovations / Innovation through Gender'

Gendered innovation 1:
Studying sex differences in immune responses

Sex differences in immune responses have been reported in infectious diseases, autoimmunity and inflammation. Females appear to respond more vigorously to viral infections and produce more antibodies in response to infection and vaccination (Klein and Flanagan, 2016).

The mechanisms leading to these differences can be hormonal (i.e. the different effects of testosterone, oestrogens or progesterone), genetic (biological females have two X chromosomes while males have only one) or related to differences in intestinal bacteria. A more vigorous immune response may induce a higher risk of autoimmune disease in females, but also a better capacity to fight infection. Initial studies report a higher production of certain subtypes of antibodies, called IgGs, in females than in males after infection with SARS-CoV2 (Zeng et al., 2020).

These differences might be relevant to the sensitivity and specificity of serological tests. The receptor used by the virus to infect host cells is the ACE2 receptor. This molecule is encoded on the X chromosome and influenced by oestrogens and androgens circulating in the body (Bukowska et al., 2017).

This means that responses to the virus and to therapies may vary, especially for groups undergoing hormonal therapies, either after menopause or to align their physical appearance with their gender identity. The possible influence of oestrogens and progesterone on the body's response to COVID-19 in people of any gender is currently being investigated in two small trials in the United States (NCT04359329 and NCT04365127).

Gendered innovation 2:
Focusing on dosing and sex-specific side effects of vaccines and therapeutics

Women appear to experience a higher overall incidence of medication side effects than men. This might be related to biological differences, differences in therapeutic choices or differences in reporting (see case study 'Prescription drugs' above). Potential sex differences in response to and the efficacy of novel therapies and vaccines need to be taken into account (Tannenbaum et al., 2017). Different doses of vaccine may be needed for females and males, and side effects may occur at different rates.

For example, females are at higher risk of developing irregularities in heart rhythm (QT prolongation) due to physiological differences in the heartbeat (see case study 'Heart disease in diverse populations'). This risk increases with the use of heart medication and many other therapies, such as hydroxychloroquine and azithromycin, currently being tested for use against COVID-19.

In addition, sex-specific issues, such as the provision of potentially life-saving therapies to pregnant women while preventing foetal complications, need to be considered in the design of clinical trials. This is particularly relevant in countries with limited healthcare resources,

and where fertility rates might be higher, thus significantly increasing the numbers of potentially pregnant COVID-19 patients.

The Horizon 2020 project Improving the guidelines for informed consent (i-Consent; i-Consent, 2020) investigates the intersection of the gender dimension and ethics in informed consent. It addresses the relationship between ethics and safety when people are participating in clinical trials, including co-decision-making between partners and the impact of self-determination and power (Persampieri, 2019).
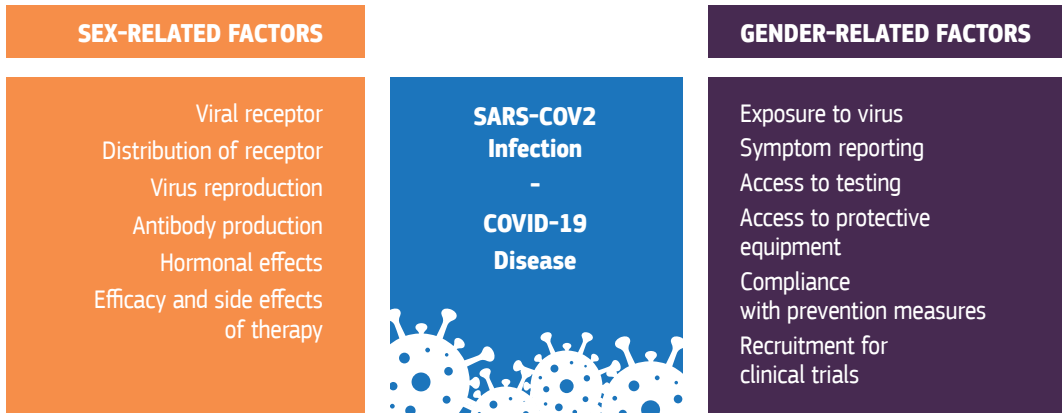

 # Method: analysing sex

All data related to COVID-19 morbidity and mortality should be disaggregated by sex (Wenham et al., 2020). Females generally respond more intensely to contact with viruses such as SARS-CoV2, including both natural infection and vaccination (Klein and Flanagan, 2016), and the potential impacts of these differences should be considered in:

▸ identifying and reporting symptoms,

▸ developing diagnostics and testing,

▸ validating therapeutics.

All study of COVID-19 needs to integrate sex as a biological variable. This includes using female and male cells and experimental animals in drug discovery and development and in preclinical research, as well as using women and men in clinical trials. Females develop side effects to medications more frequently than males (Obias-Manno et al., 2007), and all drug and vaccine trials for COVID-19 should include sex-specific analyses.

SEX AND GENDER AS POSSIBLE MODULATORS OF COVID-19

SEX-RELATED FACTORS		GENDER-RELATED FACTORS
Viral receptor Distribution of receptor Virus reproduction Antibody production Hormonal effects Efficacy and side effects of therapy	**SARS-COV2 Infection – COVID-19 Disease**	Exposure to virus Symptom reporting Access to testing Access to protective equipment Compliance with prevention measures Recruitment for clinical trials

Sex and gender as possible modulators of COVID-19.
© Sabine Oertelt-Prigione

Gendered innovation 3:
Consider gender-specific risk factors

Worldwide, women are more frequently employed in service professions, including healthcare. According to the European Institute of Gender Equality, women represent 76 % of the 49 million healthcare workers in the EU (European Institute of Gender Equality). Care professionals in hospitals, nursing homes and the community come into contact with the virus much more frequently than the general population. They are exposed to large numbers of SARS-CoV2 patients and may be exposed to higher concentrations of the virus (Liu et al., 2020). Women also perform the majority of caring duties in families and immediate communities.

Professional and private risks need to be factored into public health strategies. Healthcare workers are preferentially tested for SARS-CoV2, but is equitable access provided for informal caregivers and healthcare workers outside of hospitals? Is gender-sensitive budgeting applied in allocating emergency resources? Is personal protective equipment provided fairly to all individuals at comparable risk in healthcare institutions?

In addition to healthcare professionals, cleaning personnel and janitorial staff tend to be overexposed to the virus and require protective equipment. When developing personal protective equipment, anatomical differences need to be analysed to ensure proper fit and to avoid ergonomic difficulties (Sutton et al., 2014); gender-specific user preferences should also be considered (Tannenbaum et al., 2019).

An example of how an acute situation like the COVID-19 pandemic can be integrated into ongoing structural gender-mainstreaming activities is provided by the Horizon 2020 project Communities of practice for accelerating gender equality and institutional change in research and innovation across Europe (ACT; ACT, 2020). ACT has developed a platform for communities of practice on gender equality in research organisations and has recently used its platform to host webinars offering insight into the gender dimensions of research funded on the pandemic.

Gendered innovation 4:
Design gender-sensitive prevention campaigns

Public health strategies to contain the spread of SARS-CoV2 include containing coughing and sneezing, social/physical distancing and frequent hand washing. Gender differences in the uptake of hand hygiene have been reported in the past and these findings should be incorporated into the design of preventative SARS-CoV2/COVID-19 campaigns.

Women in the general population wash their hands more frequently than men after using a bathroom (Borchgrevink et al., 2013) and women healthcare workers wash their hands more often than their male colleagues (Szilagyi et al., 2013). When investigating the gender-specific incentives for hand washing, it appears that women respond more to knowledge-based approaches (Suen et al., 2019), while men respond more to disgust (Judah et al., 2009). This means that innovations are required to engage men in more active hand washing.

For effective public health campaigns, gender-specific preferences should be analysed and deployed in digital platforms, data collection wearables and artificial intelligence prediction models.

Gender differences are not just relevant for disease-specific prevention, but also for the management of general risk factors, such as smoking, obesity and diabetes. Smoking has been reported as a significant risk factor for severe COVID-19 disease (Guan et al., 2020) and is more common in men worldwide, although this difference is reducing in some countries.

Method: analysing gender

Preventative measures should be designed in a gender-sensitive manner to reach everyone in the community. Women reportedly comply more with hand hygiene guidelines (Borchgrevink et al., 2013), and incentives to encourage such preventative behaviours should be gender-sensitive (Judah et al., 2009).
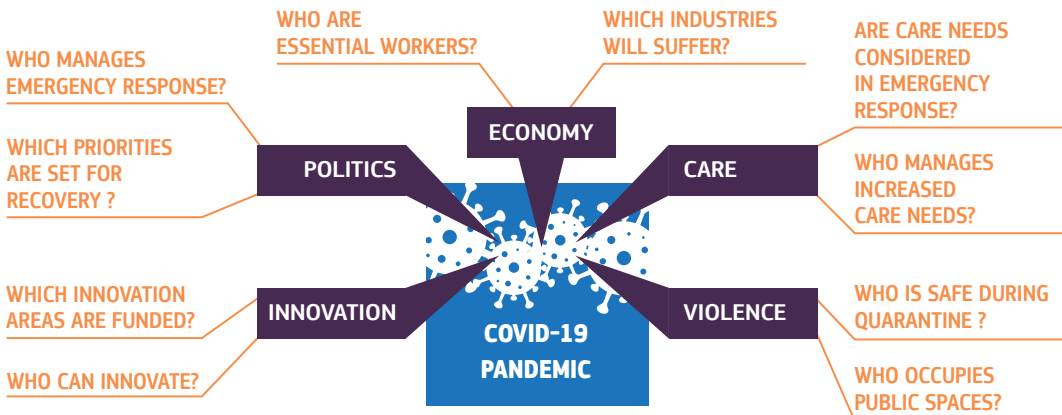Gender affects the division of labour and care duties in families and communities. Women are more frequently employed in professions with a high risk of infection, such as healthcare, and are more frequently responsible for the care of sick family members (International Labour Organization, 2016).
The design of personal protective equipment needs to take anatomical differences into consideration as well as users' gendered preferences. The allocation of protective equipment, therapies and financial aid should be gender-equitable.
Finally, gender-sensitive design should be employed when developing digital platforms for preventative measures.

GENDER-SENSITIVE IMPACT OF PANDEMICS

WHO MANAGES EMERGENCY RESPONSE?

WHICH PRIORITIES ARE SET FOR RECOVERY ?

WHO ARE ESSENTIAL WORKERS?

WHICH INDUSTRIES WILL SUFFER?

ARE CARE NEEDS CONSIDERED IN EMERGENCY RESPONSE?

WHO MANAGES INCREASED CARE NEEDS?

WHICH INNOVATION AREAS ARE FUNDED?

WHO CAN INNOVATE?

WHO IS SAFE DURING QUARANTINE ?

WHO OCCUPIES PUBLIC SPACES?

POLITICS

ECONOMY

CARE

INNOVATION

VIOLENCE

COVID-19 PANDEMIC

Gender-sensitive impact of pandemics.
© Sabine Oertelt-Prigione

Gendered innovation 5:
Considering the gender-specific socioeconomic burden of public safety measures

Limiting physical contact is important in pandemics involving viral and bacterial agents that are transmitted person-to-person. A highly transmittable airborne virus, such as SARS-CoV2, has led to social/physical distancing measures and quarantines in many parts of the world. In most parts of the world, women are more likely than men to be non-salaried employees or self-employed. They also are more likely to work in the service industries, such as care, wellness, cleaning and food handling (International Labour Organization, 2016).

The enforced closure of the service industry during quarantine has impacted the non-traditional workforce in two distinct ways: 'non-essential' workers lose their jobs, leaving individuals dependent on economic support from partners, families and the state; 'essential' workers are required to continue their activities under significant physical and psychological stress. Both scenarios have the potential to shift established gender roles and to lead to a surge in stress, existential fears and violence in public and domestic settings (van Gelder et al., 2020). Understanding and empathising with potential survivors is an essential aspect of prevention that has been addressed innovatively in the Horizon 2020 project VRespect.Me (VRespect.Me, 2019), which developed a training app using virtual reality to place perpetrators of domestic violence in the position of victims (Seinfeld et al., 2018).

Socioeconomic measures also harbour the potential to exacerbate existing inequalities. The design of solutions should be intersectional (see 'Intersectional approaches' in Annex B), including dimensions such as social origin and ethnicity/migration, among others. The European Research Council project Gender differences: a macroeconomic perspective (Gendermacro;

Gendermacro, 2017) investigated the complex interconnections between female empowerment and household economics. Simply providing resources to a female household member might lead to unexpected negative consequences if gender dynamics, such as power relations, role assumptions and priorities, are not taken into account (Doepke and Tertilt, 2011). These findings are essential for the development of gender-sensitive policies to improve the economic situation for all household members, especially in times of crisis such as the COVID-19 pandemic.

Service restrictions affect many domains in a gendered manner, but are especially relevant in healthcare. Emergency departments worldwide are reporting a reduction in demand not related to COVID-19, sparking concerns about the potential lack of treatment of medical emergencies, such as heart attack and strokes (Tam et al., 2020). Routine reproductive healthcare might also suffer. Political decisions taken on health priorities in several countries have already affected access to contraception as well as to medically assisted reproduction and safe abortions.

Conclusions

The SARS-CoV2/COVID-19 pandemic highlights the urgent need to incorporate sex and gender analysis into research and innovation processes. More men than women appear to die of the disease, but women are more frequently employed in high-risk jobs and disproportionately responsible for caring for those who are unwell. Sex differences in immunology and response to therapies can help elucidate disease-specific pathways, which could benefit everyone. Considering the gender dimensions of the pandemic could help mitigate the acute and long-term inequities that stem from its socioeconomic consequences.

>> Next steps for SARS-CoV2/ COVID-19 national and EU-funded research

Sex as a biological variable needs to be integrated into research on SARS-CoV2 infection patterns, the development of the disease and COVID-19 treatments. COVID-19 pathology demonstrates sex differences in host susceptibility and clinical course. Including sex analysis in all reporting can offer new insights for the development of targeted therapies.

Sex needs to be recorded in all COVID-19 clinical trials. This should not be limited to balanced participant rates but, most importantly, should include sex-disaggregated reporting of response, side effects, dosage adaptations and long-term effects.

Approaches to prevention should be gender-sensitive to ensure broad adoption. SARS-CoV2 is projected to circulate in the general population for some time, and there is currently uncertainty about the extent and duration of immunity. Preventative measures, such as hand washing and the mandatory wearing of masks, should be implemented in a gender-sensitive fashion, and personal protective equipment used should be designed for a range of users. The development of digital preventative solutions should focus on gender preferences and barriers. Aspects relating to domestic and gender-based violence have been highlighted in the recent **EUvsVirus hackathon** and tandem **Move It Forward for Women vs. COVID19 hackathon**.

The gender dimensions of the outbreak in terms of unemployment, care duties and associated social inequity need to be considered for long-term management of the disease and for economic re-entry strategies. Gender impact assessments (see 'Gender impact assessment' in Annex B) of proposed policies should be conducted. Adequate access to social, economic and health services needs to be ensured for all.

Targeted impact-oriented recommendations for future research and innovation actions under Horizon Europe

Cluster 1: Health

1. Staying healthy in a rapidly changing society

People need to be able to trust that COVID-19 therapies have been tested in both sexes and are safe for both sexes. Investigators and the pharmaceutical industry should report disaggregated data at all levels.

Information that has not been validated is circulating widely about COVID-19. Health literacy is therefore of utmost importance for EU citizens. Critical assessment and the ability to identify reliable sources of information needs to be promoted.

Tailored prevention strategies need to be sex-sensitive and gender-sensitive.

2. Living and working in a health-promoting environment

Personal protective equipment in the form of masks, gowns, gloves and so on is essential. This equipment needs to fit all users. Anatomical differences and user preferences should be taken into consideration when designing such equipment.

Living arrangements and resources are potentially unequally distributed in the population. This might be true across gender, age and social status boundaries. Health-promoting strategies need to take these differences into account and mitigate against the associated risks.

3. Tackling diseases and reducing the burden of disease

COVID-19 appears to affect infected females and males differently. Higher mortality rates in men have been reported in almost all countries that provide sex-disaggregated data. To understand these differences and possibly reduce

higher mortality in men, sex- and gender-sensitive research is needed.

Research needs to address the biological sex differences relevant to the disease and the gendered factors that can modulate its expression and severity.

4. Ensuring access to innovative, sustainable and high-quality healthcare

Healthcare systems differ between Member States and these differences can disproportionately affect vulnerable individuals. Vulnerability can be linked to gender, age and educational or socioeconomic status. These differences need to be taken into account in future planning and the potential restructuring of healthcare.

Nurses and other healthcare professionals are disproportionately exposed to SARS-CoV2. This workforce is predominantly female. Healthcare needs to take this gender divide into account to guarantee the safety, recognition and support of essential healthcare workers.

5. Unlocking the full potential of new tools, technologies and digital solutions for a healthy society

Access to and use of digital solutions might differ by gender. This applies to the availability of devices and to user preferences in design. Future projects need to guarantee equal access for all.

Safety has to be guaranteed for all users, regardless of their gender. Contact-tracing apps will record potentially sensitive data that could put at risk individuals that have experienced gender-based discrimination. This needs to be explicitly addressed and taken into consideration in the case of massive rollout.

6. Maintaining an innovative, sustainable and globally competitive health industry

Health research and innovation activities need to include innovators and entrepreneurs of all genders, especially in times of crisis. Access to information, networking and funding needs to be ensured. Time constraints related to care du-

ties should be offset by ad hoc funding, e.g. for childcare.

In times of crisis, innovators strive to minimise time to market. While this is important, it should not jeopardise thorough sex-sensitive and gender-sensitive development and testing processes.

Cluster 2: Culture, creativity and inclusive society

Social and economic transformations

The COVID-19 crisis is forging significant societal and workplace change. Gender roles in the home are either reinforced or changing out of necessity and digital infrastructures for working from home are being set up. These changes represent opportunities for wider social change in the aftermath of the pandemic. Research and policy should actively assess and harness the equalising effect of these changes.

The value and impact of work is being scrutinised in the light of a life-threatening pandemic. The 'essential' nature of many professions is becoming clear in this situation of acute stress. It is necessary to reconsider how essential some professions are, and their value, in a changing world. Both aspects have gendered dimensions that are currently neglected.

The economic downturn after the pandemic might lead to austerity policies. These should be developed and implemented with a gender focus to avoid exacerbating inequalities.

Mission on cancer

The COVID-19 pandemic is affecting cancer patients. They represent a vulnerable population with a current or previous condition, whose higher risk impacts their access to services and possibly limits their return to work. This might affect women and men differently.

Second, COVID-19 is a priority and a stressor for the healthcare system, which leads to delays in the provision of routine or scheduled care. Operations and chemotherapy may be

delayed, potentially impacting the prospects of recovery. Both these aspects need to be considered when examining the relationship between COVID-19 and cancer. One European initiative that is addressing some of these aspects is the task force on 'Gender in Oncology' convened by the European Society of Medical Oncology.

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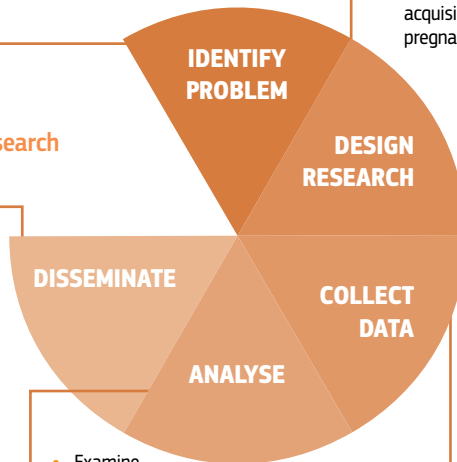
ANNEX B – DETAILED METHODS

General methods

ANALYSING SEX

- Sex may play a role in all studies involving human or non-human animals.
- Perform a literature review to identify how sex may be of relevance to your study (Moerman et al., 2009).
- Consider whether sex is a covariate, confounder, or explanatory variable.
- Consider the relevance of sex-related characteristics (e.g. genetic, physiological, hormonal, anthropometric, biomechanical, injury thresholds, levels of pain tolerance, etc.) (Tannenbaum et al., 2019).
- Consider how sex-related factors interact with gender, ethnicity, age, socioeconomic status, lifestyle, etc.
- Consider what opportunities have been missed in the past as a result of failing to analyse sex.

- Sex may serve as a direct explanatory factor or act as a potential modulator for associations between other factors; drawing a causal diagram helps make underlying assumptions explicit (see e.g. Buckley et al., 2017).
- In experimental studies, consider factorial designs to reduce the sample size required for sex-based comparisons (Buch et al. 2017; Miller et al., 2019).
- Consider how sex should be conceptualised in data collection, including physiological, hormonal, anthropometric, or biomechanical aspects (Tannenbaum et al., 2019).
- In longitudinal research, consider how reproductive history may influence the cohort under investigation; e.g. will data. acquisition be impacted if females get pregnant during the study?

ANALYSING SEX
enhances all phases of research

IDENTIFY PROBLEM

DESIGN RESEARCH

DISSEMINATE

COLLECT DATA

ANALYSE

- Report the sex of your subjects, even in single-sex studies.
- Report the sex distribution of cells, animals and humans.
- Report how information on sex was obtained.
- Disaggregate reported results by sex.
- Ensure that sex variations are properly visualised in the tables, figures, and conclusions.
- Avoid overemphasising sex differences. Are observed sex differences of practical significance? (Maney et al., 2016; Ribbon et al., 2014).
- Report all results: positive, negative, and inconclusive.
- Consider following the SAGER publication guidelines (Heidari et al., 2016).

- Examine overlaps between and variations within groups of different sexes (see, e.g., Maney et al., 2016).
- Consider the source of any sex difference observed, including the role of environmental, genetic, hormonal, or anthropometric factors.
- When examining sex differences, adjust for possible intersecting and confounding factors (e.g. age). Overlooking confounding factors may result in overemphasising sex differences.
- In longitudinal studies, examine how observed sex variations evolve over time.
- Analyse how observed sex differences may vary by factors such as age, ethnicity, socioeconomic status.

- Consider how to collect information on intersex subjects and hermaphrodite animals.
- Include adequate samples of females and males and, where relevant, intersex or hermaphrodites of different configurations.
- Record information on factors that intersect with sex (e.g. age, life-style, socioeconomic status).
- In experiments, consider how the sex of the researcher may impact research outcomes (Chapman et al., 2018).
- In survey research, questions about gender should not be used as a proxy for birth sex .
- In product and systems design, data collection must consider anthropometric, biomechanical, and physiological factors that vary by sex (Tannenbaum et al., 2019; Jingwen et al., 2012).

Related new case studies

▶ Chronic pain

▶ COVID-19

▶ Extended virtual reality

▶ Marine science

▶ Prescription drugs

▶ Systems biology

Related previous case studies

▶ Animal research

▶ Colorectal cancer

▶ De-gendering the knee

▶ Dietary assessment method

▶ Environmental chemicals

▶ Exploring markets for assistive technology for the elderly

▶ Genetics of sex determination

▶ Heart disease in diverse populations

▶ HIV microbicides

▶ Inclusive crash test dummies

▶ Osteoporosis research in men

▶ Stem cells

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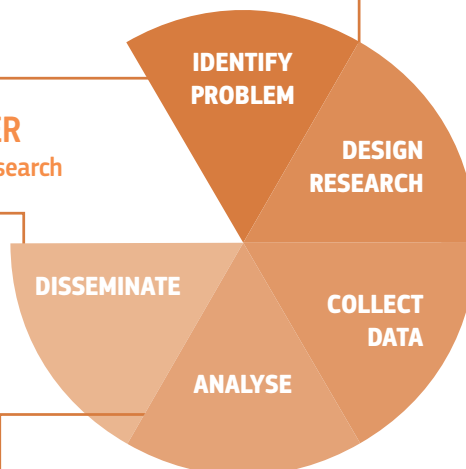
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ANALYSING GENDER

- Gender may play a role in all studies involving human (Tannenbaum et al., 2019).
- Perform literature searches with adequate terms for "gender" and "sex" (Oertelt-Prigione et al., 2010).
- Consider the project's relevance in a relation to different gender identities, norms, and relations.
- Consider relevant factors intersecting with gender (age, socio-economic status, ethnicity, etc.).
- Reflect upon your own gender assumptions in relation to the project.
- Consider what opportunities may be missed as a result of failing to analyse gender and itersecting factors.

- Consider how to involve diverse groups of research subjects/end-users at various steps in the project life-cycle to ensure inclusive solutions.
- Consider which method (qualitative and quantitative) are suited for examining the gender dimensions of relevance to your project.
- In quantitative research, calculate appropriate sample sizes for gender comparisons (Sell, 2017).
- When measuring gender in survey research, ensure that your instrument has been psychometrically validated in the target population (Steenkamp and Baumgartner, 1998).
- Inspect your analytical concepts, categories, and theoretical models for misguided or stereotypical assumptions.
- Consider the risk of stereotypical or excluding relevant groups.

ANALYSING GENDER
enhances all phases of research

IDENTIFY PROBLEM

DESIGN RESEARCH

DISSEMINATE

COLLECT DATA

ANALYSE

- Collect data across gender characteristics (e.g. gender norms, gender identities, and gender relations) in intersecting factors.
- In survey research, the two-step approach to collect use data on gender identity and birth sex (Deutsch et al., 2013). Ensure that all participants feel safe disclosing their gender identity.
- Ensure equal access for women, men and gender-diverse individuals. Is oversampling needed to ensure that a sufficient number of gender-diverse individuals participate in the study? (Vaughan, 2017).
- Consider how gender relations between researches and participants may impact the data collection (Chapman et al., 2018).

- Report sample characteristics by gender, sex, and relevance intersecting variables.
- Report how information on gender identity was obtained.
- Disaggregate reported results by sex and gender.
- Report all results positive, negative, and inconclusive.
- Ensure that gender variations are properly in tables, figures, and conclusions.
- Avoid overemphasizing gender differences. Are the observed variations of practical significance? (Nelson, 2017).
- Consider following the SAGER publication guidelines (Heidari et al., 2016).

- Conduct analyses of relevant factors related to gender norms, gender identity and gender relations (Nielsen et al., 2020).
- When using existing data consider cultural or institutional contents in which the data were generated for potentials gender biases.
- Examine similarities between groups (i.e. men, women, and gender-diverse individuals) and variations within groups (Hyde, 2005).
- Examine how observed differences between women, men and gender-diverse individuals relate to gender norms and relations.
- Examine how observed gender differences vary by factors such as age, ethnicity, socioeconomic status.
- In longitudinal studies, examine how observed gender variations evolve over time.
- In qualitative analysis, consider how gender norms, identities and relations intersect to shape people's experiences, opportunities and practices.

Related new case studies

- Agriculture
- Chronic pain
- COVID-19
- Extended virtual reality
- Facial recognition
- Fair tax
- Prescription drugs
- Quality urban space
- Smart energy solutions
- Smart mobility
- Systems biology
- Venture funding
- Virtual assistants and chatbots
- Waste management

Related previous case studies

- Climate change
- Colorectal cancer
- De-gendering the knee
- Dietary assessment method
- Exploring markets for assistive technology for the elderly
- Gendering social robots
- Haptic technology
- Heart disease in diverse populations
- HIV microbicides
- Housing and neighborhood design
- Inclusive crash test dummies
- Machine learning
- Machine translation
- Making machines talk
- Menstrual cups
- Osteoporosis research in men
- Textbooks
- Video games
- Water infrastructure

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INTERSECTIONAL APPROACHES

An intersectional approach (see Section 2.3) is important to consider when setting research priorities, developing hypotheses and formulating study designs. Taking an intersectional approach can better predict variations in health outcomes and determine user needs, and ultimately lead to more inclusive research and engineering solutions (Faulkner, 2004; Weber and Fore, 2007). For example, sex, socioeconomics, gendered divisions of labour and language interact to determine how agricultural workers are exposed to endocrine disruptors (see Gendered Innovations 1 case study 'Environmental chemicals'). Recent research also demonstrates how an intersectional approach can improve the accuracy of AI-based facial recognition (see case study 'Facial recognition') and energy-efficiency measures (see case study 'Smart energy solutions').

Identify problem

Intersectional approaches may be relevant in studies involving human subjects. While sex and gender are important concepts to consider (see 'Analysing sex' and 'Analysing gender' above), they are shaped by other social and biological factors. The way the research problem is formulated will determine which intersecting variables are required for analysis. The most important categories, factors and relationships cannot be determined a priori, but emerge in the process of investigation (Hankivsky, 2014).

Before beginning a study, researchers should conduct systematic literature searches to identify factors and categories of potential relevance. These categories and factors can be biological, sociocultural or psychological aspects of users, customers, participants, experimental subjects or cells (see box right). Even intersecting factors, such as diet or genetic variability, may be important to consider. Such factors may reveal subgroup differences among males and females that would have been obscured by using only sex as a variable (see Gendered Innovations 1 case study 'Nutrigenomics').

Factors to consider in an intersectional analysis may include:

- gender
- disabilities
- ethnicity
- race
- age
- geographic location
- socioeconomic status
- nationality
- sexual orientation
- LGBTI+ identity
- religion
- educational background
- lifestyle
- language
- family configuration
- environment
- genetics
- sex hormones
- reproductive status
- body composition
- comorbidities
- body size.

In this phase, it is also important to consider the social contexts, including societal, institutional and community-level circumstances (e.g. laws, policies, healthcare providers, school systems, law enforcement, religious institutions,

crime rates) that shape people's life experiences, opportunities and choices in different ways depending on their gender, race, socioeconomic status, sexuality, geographical location, etc. (Bowleg, 2012; Hankivsky, 2014).

Finally, it may be relevant to consider whose practical knowledge or experience is relevant to your project. Involving diverse groups of research subjects or potential end-users in the research process (from problem formulation to research design) may sharpen the intersectional analysis and lead to more inclusive solutions (see 'Co-creation and participatory research' below).

Design research

Intersectional research should be designed to illuminate the multiplicative effects of different, but interdependent, categories and factors. Determine which methods (qualitative, quantitative or mixed) are best suited to examining the intersecting variables of relevance to your project. Qualitative approaches (e.g. focus groups, document analysis, interviews and observations) can provide detailed insights into the complex web of factors, processes and relationships that shape people's identities, opportunities and practices. Quantitative methods (e.g. survey questionnaires, social-media data, product purchases and register data) allow the researcher to examine similarities and differences between groups and subgroups, and may reveal how such similarities and differences vary by social context and evolve over time (Bowleg, 2008; Shields, 2008; Else-Quest and Hyde, 2016a, 2016b). In mixed-methods designs, qualitative methods may be deployed to explore which intersectional categories, factors and relationships to examine in a subsequent quantitative analysis. Qualitative methods, however, may also be used to obtain deeper understandings of salient interactions and relationships identified in a preceding quantitative analysis. A quantitative analysis, for example, may reveal unexpected differences between women and men that cannot be explained by gender or socioeconomic status alone, such

as women of high socioeconomic status having similar health outcomes to those of men of low socioeconomic status (Sen et al., 2010). In this case, a qualitative follow-up study may help tease apart the underlying processes and mechanisms that drive the observed differences and similarities.

Consideration should always be given to the potentially dynamic nature of the intersectional categories and factors in focus. The importance of different categories and factors may vary by social context, and may change over time (Hankivsky, 2014). In quantitative research, such variations could be examined using geospatial analysis or longitudinal designs (Warner and Brown, 2011; Weber et al., 2019).

Finally, researchers using qualitative interviews or surveys should inspect their questions and categories for misguided or stereotypical assumptions, before initiating the data collection. Extensive piloting and/or cognitive interviews with the target population may improve the study's validity and reliability, and make data collection more effective.

Collect data

Applying an intersectional approach presupposes data collection on factors intersecting with sex and gender (ethnicity, religion, sexual behaviour, lifestyle, socioeconomic status, disability, gender categories relevant to transgender people, etc.).

The attention to individual-level categories and characteristics should be complemented with a focus on group-level factors (e.g. at the household, neighbourhood, institutional, regional, state or national level). Again, the relevant variables to include will depend on the problem identified for study. At the neighbourhood level, it may be relevant to include measures of air quality, crime rates, population density or housing-unit occupancy rates, etc. At the state and national levels, it may be relevant to account for factors such as healthcare policy schemes, parental-leave policies or transgender-rights legislations (Bowleg and Bauer, 2016).

In quantitative research, calculate the minimum sample size required for each group included in your analysis to allow meaningful statistical analysis (Rouhani, 2014). Strategic oversampling of some groups may be necessary to allow sufficient statistical power for cross-group comparisons and interaction analyses. Respondent-driven sampling (Heckathorn, 1997) and time-space sampling (MacKellar et al., 2007) can be used to recruit marginalised or 'hidden' populations that are difficult to access through traditional sampling methods (Bowleg and Bauer, 2016).

In qualitative research, the sample should be heterogeneous enough to capture the various intersecting positions of relevance to the research problem.

Analyse data

An intersectional analysis seeks to illuminate the multiplicative effects of different, but interdependent, categories and factors.

Quantitative research should move beyond an 'additive' focus on main effects (e.g. estimating separate effects for gender, race and sexual orientation) to examine how the variables in focus intersect (Hancock, 2007; Bauer, 2014; Bowleg and Bauer, 2016).

Multi-level models (e.g. hierarchical linear modelling) can be employed to tease out the effects of individual-level variables and group-level factors (e.g. hospital setting, neighbourhood, state or occupation) on a given outcome.

In regression models, interaction terms may be used to probe how respondents at particular locations in the intersection of two or more categories (e.g. a gay black man or a straight Asian woman) vary on a given outcome. Multiple main effects may also be used to examine such variations, if dichotomous variables are computed for each of the intersecting categories of interest (Sen et al., 2010). A medical study, for instance, examining main effects for intersecting categories related to sex and race found that the in-hospital mortality for myocardial-infarction patients showed little variation for white females, white males and black males, but was higher for black females (Vaccarino et al., 2005). This important finding could have been overlooked, had the study restricted its focus to two main effects (sex and race) rather than including dichotomous variables for each of the four locations in the intersection (white male, white female, black male, and black female) (see also Sen et al., 2010).

Qualitative analyses will often be exploratory in nature and should offer rich descriptive accounts of the various categories, factors and processes that intersect to shape people's identities, opportunities and practices in a given context (Hunting, 2014). Such an analysis should examine both commonalities and differences between categories and factors, and acknowledge within-group variations in experiences, viewpoints and behaviours. A multi-level approach, operationalised through a nested coding of the data material, may be used to explore how individual experiences and behaviours relate to broader group-level and contextual factors (Hankivsky, 2014).

Reporting and disseminating results

Reporting should specify the sample characteristics by gender, sex and relevant intersecting variables and describe how information for each variable was obtained. To promote transparency, researchers should report all relevant outcomes of the intersectional analysis, including inconclusive results. Be specific about which findings generalise broadly and which apply to specific populations, variables or geographical locations.

When reporting the results of cross-group comparisons, provide information on the within-group variability and between-group overlap of the distributions. Be cautious not to overemphasise differences between individuals or groups. Ensure that information on both differences and similarities is properly reported in the text, tables and figures, and that sensitivity to nuance is maintained throughout the report (Else-Quest and Hyde, 2016b; Cole, 2009).

In quantitative research, statistical interactions (and effect-measure modification) should be reported in sufficient detail to enable readers to interpret the effect size and practical significance of the findings (Knol and Van der Weele, 2012; Bauer, 2014).

Given the close link between intersectionality and questions of power, privilege and inequality, it is important to situate the study findings in the context of the target populations' particular societal, institutional and community-level circumstances (Bowleg, 2012; Hankivsky, 2014; Else-Quest and Hyde, 2016b).

Dissemination strategies should take into account the complexity of target audiences. Too often, researchers restrict their audience to academic peers. An intersectional approach helps sensitise the researcher to many other potential audiences.

When intersectional datasets are made open access, careful considerations about anonymity are warranted. For instance, 'anonymised' data including demographic information on postcode, birth data, ethnicity and sex may offer sufficient information for others to de-anonymise the data (Sweeney, 2002).

Related new case studies

▶ Agriculture

▶ COVID-19

▶ Facial recognition

▶ Virtual assistants and chatbots

▶ Prescription drugs

▶ Quality urban spaces

▶ Smart energy solutions

▶ Systems biology

Related previous case studies

▶ Climate change

▶ Colorectal cancer

▶ De-gendering the knee

▶ Gendering social robots

▶ Heart disease in diverse populations

▶ Inclusive crash test dummies

▶ Machine learning

▶ Osteoporosis research in men

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CO-CREATION AND PARTICIPATORY RESEARCH

Co-creation and participatory research are used in a wide range of fields, including industrial product design, epidemiology and software engineering. Although specific methodologies are diverse, co-creation and participatory approaches involve a diverse group of consumers, citizens, interest groups or research participants in tasks such as setting research objectives, gathering and processing data, interpreting results and implementing solutions (Leung et al., 2004; Gonsalves et al., 2005; Hoyer et al., 2010; Voorberg et al., 2015; Greenhalgh et al., 2016; Smith et al., 2017). Co-creation and participatory research typically seek to balance interests, benefits and responsibilities between the relevant stakeholders, sharpen attention to user needs, and make the whole process transparent and inclusive, from planning to implementation (WHO, 2011).

Practical steps for incorporating sex and gender analysis into participatory research

Researchers and designers should take these steps.

1. **Identify the area of work or everyday life they wish to address.** Investigate gendered structures in that area. What opportunities may have been missed in the past as a result of failing to analyse sex and gender? For instance, in transportation planning and housing and neighbourhood design, it will be critical to consider the mobility of care (see case study 'Smart mobility'), and how needs with respect to built environments vary by gender roles and gendered divisions of labour (see Gendered Innovations 1 case study 'Housing and neighbourhood design').

2. **Identify potential target groups.** Conduct literature reviews, assemble focus groups, send out questionnaires (see 'Asking about gender and sex in surveys' below), carry out ethnographic observations, etc. What are the characteristics of target users/communities (these may include sex, age, socioeconomic status, ethnicity, native language, etc.)? Questions include the following: How will different groups of people (defined by sex, race, age, geographical location, etc.) be affected by this project/product? What are their particular perspectives, needs and interests? Whose practical knowledge or experience is relevant to this research or design project? For example, in sub-Saharan Africa (where women are typically responsible for fetching water), tapping into women's knowledge about soils and their water yields may be critical to ensuring the success and sustainability of community-managed water services (see Gendered Innovations 1 case study 'Water infrastructure'). Similarly, involving gender-diverse groups of elderly people and their caregivers in the development of assistive technologies can ensure solutions that are useful to a broad user base (see Gendered Innovations 1 case study 'Assistive technologies for the elderly').

As an alternative to direct user involvement, developers may create personas (see case studies 'Smart energy solutions', 'Smart mobility' and 'Quality urban spaces' above). Personas are fictitious representations of typical (or atypical) target populations derived from data about these actors' common traits and characteristics (Miaskiewicz and Kozar, 2011). They are used as model characters or benchmarks for the user experience, which focus the design on the people whom the planned project seeks to benefit. An important consideration when developing personas is to avoid reinforcing stereotypes with respect to gender, race, age, etc., as this may end up constraining the uptake of your product, service or solution (Turner and Turner, 2011; Hill et al., 2017).

3. **Seek user or community input.** Engage users/communities in defining problems, requirements, and solution and design alternatives (Oudshoorn et al., 2002, 2003). Ensure that your participant sample is heterogeneous enough to capture the various intersecting positions of relevance to your project (see 'Intersectional approaches' above). Involving users who vary in gender, ethnicity, age and socioeconomic status allows researchers and engineers to gather information about how a technology, product or public health measure will affect people's everyday lives, assist their work or enhance their leisure.

4. **Observe workers or users.** Observing people at work allows scientists and engineers to access tacit knowledge: knowledge that workers regard as self-evident or take for granted and rarely articulate. Capturing tacit knowledge may bring new perspectives to formal research and design. Researchers might ask: How do sex and gender influence how the work is done, how an artefact is used or how a process works? How may this differ in a single-sex versus mixed-sex context? Engineers and designers can probe their understandings of work processes in interaction with users. For example, to develop new software for customer-service call centres, ICT researchers observed, interviewed and worked with call centre employees – a majority of them women – to understand their needs. Analysing the gendered nature of the work and gathering user input produced software that better captured previously unrecognised needs (Maass and Rommes, 2007).

5. **Evaluate and redesign.** Researchers can cooperate with users/communities in all steps of project evaluation, from defining goals or measures of success to determining if these goals have been achieved in the design, implementation and monitoring steps (WHO, 2002; see 'Gender impact assessment' below). User and community input can also help to guide product redesign and further research.

Related new case studies

▶ Agriculture

▶ Smart energy solutions

▶ Quality urban spaces

▶ Smart mobility

▶ Waste management

Related previous case studies

▶ Housing and neighborhood design

▶ Water infrastructure

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ASKING ABOUT GENDER AND SEX IN SURVEYS

Most survey questionnaires in the social sciences, health sciences, civil engineering, city planning, etc. include a demographic question about sex or gender. Traditionally, survey-based items about sex or gender have asked the respondents to indicate whether they were male or female (Box 1). This method, however, has been criticised for conceptual slippage, inaccuracy and inability to capture the complexities of gender and sex identities. Conflating birth sex and gender identity in questionnaires can lower the precision and relevance of survey research for policy development and innovation.

Box 1. The one-step method (example)

Are you male or female?

☐ Male

☐ Female

Source: American National Election Survey 2008–2009 (Westbrook and Saperstein, 2015)

In a review of major US social surveys, Westbrook and Saperstein (2015, p. 535) found that the extant one-step method tends to 'conflate sex and gender and treat the resulting conceptual muddle as a starkly dichotomous, biologically fixed, and empirically obvious characteristic'. Surveys that employ the one-step method tend to use sex and gender as interchangeable terms or leave unspecified which of the two they are asking about (Box 1). Further, this method presumes a concordance between the respondent's birth sex and current gender identity that makes it impossible for survey analysts to differentiate between cisgender and transgender populations (see Sections 2.1 and 2.2).

One-step measures typically also restrict the available response options to mutually exclusive, binary categories (female/male, or woman/man) (Westbrook and Saperstein, 2015). By doing so, they implicitly perpetuate stereotypical conceptions of sex and/or gender, and make invisible gender-diverse individuals who do not identify with female/male and women/man categories.

To remedy these shortcomings, researchers have developed a two-step method that measures birth sex and current gender identity separately (Melendez et al., 2006; Deutsch et al., 2013; GenIUSS Group, 2014). The two-step method has been tested in transgender populations and validated in broader North American populations, with good results (Tate et al., 2013; GenIUSS Group, 2014; Reisner et al., 2014; Magliozzi et al., 2016; Saperstein and Westbrook, 2018).

This method (Box 2) has several advantages. It allows survey researchers to infer transgender identity indirectly when a respondent's birth sex does not match the reported gender identity (e.g. when a respondent ticks 'male' in the birth sex question and 'woman' in the gender identity question) (Magliozzi et al., 2016). Moreover, it expands the number of response options available to the survey participants. In addition to the response categories 'female and 'male', the birth-sex question in Box 2 includes 'intersex' and 'sex not listed here' (with an open response option). Likewise, the current gender identity question lists 'non-binary', 'genderqueer' and 'a gender identity not listed here' (with an open response option) as possible response options.

Box 2. The two-step method

Birth Sex

What sex were you assigned at birth?

☐ Female

☐ Male

☐ Intersex

☐ A sex not listed here
(please specify)

_____

☐ Prefer not to state

Current Gender Identity

What is your current gender identity?
(Please select all that apply)

☐ Woman

☐ Man

☐ Non-binary

☐ Genderqueer

☐ A gender identity not listed here
(please specify)

_____

☐ Prefer not to state

Sources: adapted from Magliozzi et al. (2016)
and GenIUSS Group (2014)

Note here that the response options for birth sex include the biological terms 'female' and 'male', while the question about current gender identity lists the gender terms 'woman' and 'man' (Box 2). This terminological distinction is important, as it helps signal to respondents the conceptual difference between birth sex and current gender identity (see Sections 2.1 and 2.2). However, this distinction is not possible in languages that use a single term to refer to both sex and gender identity. For instance, Danish, Norwegian and Swedish do not have separate terms for sex and gender identity, and do not distinguish between the biological terms 'female' and 'male' and the gender

terms 'woman' and 'man'. Survey researchers in these countries can, however, still make use of the two-step approach to separate birth sex and current gender identity.

Individuals who do not identify with binary gender categories (woman or man) may use a variety of terms to express their gender identity (e.g. non-binary, genderqueer, gender-nonconforming, agender) (Factor and Rothblum, 2008; Magliozzi et al., 2016; Scheuderman et al., 2019). The meaning and prevalence of these gender expressions tend to change over time and to vary by language and cultural context (Factor and Rothblum, 2008; GenIUSS Group, 2014; Jans et al., 2015).

This introduces a challenge for survey researchers. No matter how many response options a survey provides, it will never be possible to fully cover the gamut of gendered self-expressions (Magliozzi et al., 2016). This challenge can be resolved by including open-ended response options (Box 2). To allow meaningful statistical comparison, however, survey analysts may need to subsume such open-ended expressions within broader categories before analysing the data (Magliozzi et al., 2016).

Data from respondents who do not identify with binary gender categories or from intersex individuals should not simply be removed from the analysis, but should be handled in accordance with pre-planned protocols. To allow meaningful statistical analysis, researchers should consider oversampling non-binary and intersex individuals in the data collection process (see 'Analysing gender in health and biomedicine' and 'Analysing sex in biomedicine' below).

Recently, researchers have begun to explore more fine-grained, multifactorial measures of gender in survey questionnaires (Pilote and Karp, 2012; Magliozzi et al., 2016; Saperstein and Westbrook, 2018; Nielsen et al., 2020). The use of such measures may allow more precise knowledge of specific gender-related attitudes and behaviours.

Related new case studies

▶ Quality urban spaces

▶ Smart energy solutions

▶ Smart mobility

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Field-specific methods

Health and biomedicine

ANALYSING GENDER IN HEALTH AND BIOMEDICINE

In addition to analysing sex, research involving human participants should consider the role of gender as a potential causal and modulating factor (Clayton, 2016; Clayton and Tannenbaum, 2016; Tannenbaum et al., 2016, 2019). Gender norms, gender identities and gender relations impact social interactions, communication, access to resources and coping strategies. These factors can influence whether or not patients are offered participation in a study, whether or not they can reach the study site, the way they present their symptoms and the way physicians respond to them. Gender can influence the therapies offered to patients and their long-term response to those therapies (Oertelt-Prigione and Regitz-Zagrosek, 2012; Schenck-Gustaffson, 2012). There may also be gender bias in survey and diagnostic questions. Gender is a social determinant of health and as such a potential cause of health disparities (Dahlgren and Whitehead, 1991). Resources are available to support researchers in developing a robust literature search for sex and gender factors in health and biomedicine (Moerman et al., 2009; Oertelt-Prigione et al., 2010).

Specify research focus and formulate hypotheses

▶ Gender is a multidimensional concept, which includes gender norms, gender identity and gender relations (Nielsen et al., 2020). **Gender norms** consist of spoken and unspoken rules produced through social institutions, such as the family and workplace, and cultural products, such as technology and social media. **Gender identity** refers to how individuals and groups perceive and present themselves in relation to gender norms. **Gender relations** are how

individuals interact with other people and institutions in specific sociocultural contexts. In health, all cases may apply, but frequently one dimension is more relevant than the others to the specific question asked.

Choose the most relevant gender dimension for the proposed research

▶ Researchers should first identify which dimensions of gender are most relevant to their work and select appropriate instruments to capture any that are relevant. In recent years, some instruments have been developed that group two or more dimensions (Tate et al., 2014; Pelletier et al., 2015; Nielsen et al., 2020). There is marginal overlap between the instruments currently available, so researchers need to make an informed choice. Sometimes a single in-depth instrument may be a better option than a more comprehensive one that offers less differentiated output. Intersectional aspects will most probably play a role as well. Depending on the research question, factors intersecting with sex and gender, such as ethnicity or socioeconomic status (see 'Intersectional approaches' above), should be considered.

- **Gender identity of the participants.** A broad array of gender identities exists, and they are evolving over time. Researchers need to find a balance between inclusion and practicality. Three categories (man, woman, and non-binary or gender diverse) may be more suitable for analysis than six or

seven; however, making this choice may exclude some participants. Researchers should spend some time defining if and how gender-diverse populations will be identified for recruitment while avoiding stereotyping and discrimination. Some consideration should also be given to the study population and their potential resistance to modern concepts of gender as asked in the study. Which questionnaires are acceptable for which population? Extensive piloting with the target population is advisable when new methods are employed; some degree of resistance can be expected.

- **Gender norms and relations.** In choosing the type of study, some thought should be given to the potentially dynamic nature of gendered norms and behaviours. Gender norms and behaviours change over time and depend on the societal and cultural context. The experiences of a gay black man in an urban context differ from those of a straight Asian woman in a rural setting. Nevertheless, the gender-related reality of both these individuals has changed over the last two decades. Is this potentially relevant to the research, and can researchers account for it?

- **Gender identity and norms of the researchers.** Finally, the gender identity of investigators and the gender norms they experience could also be a factor. Gender norms and relations play out in interactions between participants and researchers. Collecting data on only participants may limit opportunities for investigation.

Research design

The impact of gender on the research question can be addressed in quantitative, qualitative or mixed-method studies. Quantitative data will offer highly standardised and comparable responses in different studies. If deeper insight into motivations, contextual factors and situated experiences and realities is needed, qualitative data may be a better option. Qualitative data may supplement quantitative findings to better understand outliers or missing data, or to explore the accuracy of the quantitative tools in certain subpopulations. Especially in exploring gender-diverse populations, whose health needs have largely been ignored, qualitative research or a mixed-method design may be a better fit.

▶ **Explanation of gender terms.** Participants may not be familiar with the concept of gender and may question its use. It may be advisable to explain why gender is a research component.

▶ **Sampling consideration.** How will the inclusion of a sufficient number of gender-diverse individuals be guaranteed? Will this affect a randomised design? Researchers should consider the opportunity for strategic oversampling in order to allow meaningful statistical analysis.

▶ **Controls.** If controls will be used in the study, how will these individuals be selected? Comparisons can include women/men dyads, women/men/gender-diverse triads or multiple combinations thereof. One should consider that women, men and gender-diverse populations are heterogeneous in themselves, so multiple layers of differentiation may need to be applied to identify suitable control individuals.

▶ **Instrument bias.** Many instruments have been designed without attention to the potential role of gender norms and relations. They may therefore introduce unexpected bias. If, for example, crying is not compatible with a strong masculine gender identity, an individual may not respond to a question about frequency of crying in a depression questionnaire

and may therefore not be diagnosed appropriately. If questionnaires enforce gender-stereotypical norms about care and professional obligations, the double burden of work and care may be underestimated in an individual who does not conform to a normative gender role.

▶ **Participation and access.** When developing the study protocol, gender as a potential modulator for participation and access should be taken into account. Will participants answer questionnaires by post, in a normal healthcare context or at a study site? In many regions, women have less access to transportation or childcare, and reaching study sites may be more challenging. Researchers should consider this in planning their study and evaluate options to minimise such barriers. Safety is also relevant. Disclosing a non-binary gender identity may pose a risk in some contexts. A clear safety protocol should be developed.

Analyse data

The fundamental requirement for statistical analysis is an adequately large sample and an appropriate number of outcomes to guarantee the power of the analysis. Researchers should reflect on the distribution of outcomes and con-sider oversampling, if outcomes are not equally distributed between genders. Specifically, a low number of participating gender-diverse sub-jects will affect the analysis of this subgroup. These individuals are frequently treated as out-liers and excluded from the analysis. Ways to meaningfully include information about their experiences should be considered a priori.

▶ **Multiple instruments.** If multiple instruments will be used to determine different dimensions of gender (identity, norms, relations), these may have to be weighted for analysis. Choice of instruments will also influence whether variables will be nominal or continuous. This will affect the type of analysis performed, since many methods traditionally used in biomedicine are designed for dichotomous outcomes. This also applies when aggregate scores are being used. The hierarchical order of this analysis should be defined a priori to avoid the introduction of potential sources of bias.

▶ **Sex and gender interact.** A possible interaction between sex and gender can be expected in human subjects. Will this be part of the analysis and will this interaction be explicitly analysed? In addition to the interaction of sex and gender, other factors intersecting with gender may need to be included in the analysis. In many cases, gender will play a role in both explaining the results and acting as a potential modulator for other causal pathways. Nevertheless, most studies will allow only the description of correlation rather than causality. The structural interactions of other dimensions, i.e. work, education, (dis)ability and ethnicity, with gender should be considered, and analysis should reflect how these have been taken into account. The design of these analyses can vary from multiple stratifications to the inclusion of interacting terms to complex factorial designs.

▶ **Qualitative data.** Qualitative data analysis can be exploratory or confirmatory in nature, based on the study design and research objectives. Gender needs to be considered as an important modulator in all research contexts. It is important to consider how gender may not just modify relations between individuals in isolation, but also interact with age, hierarchies, socioeconomic means, etc. Identifying outliers in qualitative analyses, i.e. individuals who do not conform to the majority of the population, often provides a better understanding of the gender norms

and relations at play. These aspects can also be identified by addressing underlying domains, such as gendered language and gendered themes. How participants and patients describe their symptoms and experiences can differ significantly depending on prevailing gender norms and can have an effect on the diagnostic and therapeutic options provided.

▶ **Mixed methods.** In mixed-method sequential designs in which qualitative approaches are followed by quantitative ones, qualitative data analysis may be used to identify which gender variables to include in the quantitative part. In sequential designs that use qualitative approaches to explore findings from quantitative data, such analysis aims to bring a better understanding of drivers of observed statistical differences. For example, if quantitative data reveal that health outcomes differ between partnered women with children and single women with children, qualitative data may be used to understand what dimensions of partnership explain the observed difference.

▶ **Other analysis.** Analysis of verbal and non-verbal gendered body language, tone of voice and interactions may be appropriate. A social science perspective is particularly helpful for analysing gender through qualitative methods.

▶ **Secondary data analysis.** The growing number of internationally available cohort studies offers an opportunity for post hoc analysis of gender-correlated variables. Although this option is limited compared with the strategic inclusion of gender variables when designing research, it still provides pilot data that may be valuable for identifying follow-up studies. Some options for the development of proxy measures based on existing variables within cohort studies have been reported

(Pelletier, 2015; Nielsen, 2020) and more are under way. The most basic indicators used are education, professional status, and individual or household income. However, more complex measures, such as care responsibilities and their timing, role behaviour, stress, anxiety and depression have also been suggested.

Reporting and disseminating results

▶ **Formats for reporting.** Some granting agencies and peer-reviewed journals require the reporting of gender in addition to sex (see Chapter 5, 'Policy recommendations for Horizon Europe'), yet there is currently no standard for reporting gender. Reporting should offer enough detail to support reproducibility. Researchers should consider following the Sex and Gender Equity in Research (SAGER) guidelines (Heidari et al., 2016) for general publications and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and Consolidated Standards of Reporting Trials (CONSORT) equity guidelines (Welch et al., 2016, 2017) when reporting clinical trials. The PRISMA and CONSORT guidelines have been designed for the reporting of sex and potential intersecting factors but can be applied to the reporting of gender.

▶ **Report null findings.** Researchers should report when gender differences (main or interaction effects) are not detected in their analyses, in order to reduce publication bias, an important consideration in meta-analyses (IOM, 2012). If gender-diverse individuals are not oversampled, they may form a small subgroup of the study population and preclude comprehensive statistical testing because of a lack of power. In this case, descriptive statistics should still be reported to allow potential pooled analysis in the future.

Box 3. Checklist for integrating gender into health and biomedicine research design

Choice of instrument	• Which dimension of gender should be measured (identity, norms, relations)?
	• Will an instrument be selected for each gender dimension to be measured or will a combined instrument be used? Single instruments allow more detailed capture of potential associations with the outcome, but may be unwieldy.
	• Have you chosen instruments that can capture how gender norms and behaviours change over time?
	• Is the chosen instrument sensitive to the norms of the culture(s) in which it will be deployed?
	• Was the instrument validated for different populations? Is there gender bias in the way the questions were formulated?
Application of the instrument	• Are the categories of gender identity inclusive and practical for analysis?
	• How can gender-diverse populations be identified without stereotyping and discrimination?
	• Which questionnaires are acceptable for which populations? Can researchers find a balance between using innovative concepts of gender and potentially losing participants who might have reservations about these topics?
	• Will the questions be self-administered or administered by a research assistant? Have gender relations between participant and researcher been considered?
Study type	• Is a quantitative, qualitative or mixed-method approach most appropriate?
	• What type of study is needed to address the specified research hypothesis (cross-sectional, longitudinal, observational or interventional studies)?
	• Is a case–control study planned? If controls are being used, how are they selected? Who are the controls and what are controls matched on?
	• Are intersecting factors, such as age, education and socioeconomic status, being considered?
	• Are gender-diverse populations being included in the sample?
Study protocol	• Is an explanation needed for participants about why gender is being researched?
	• How will the inclusion of a sufficient number of gender-diverse individuals be guaranteed? Will this affect a randomised design?
	• Is the relative oversampling of gender-diverse populations and minorities warranted?

- Has gender been considered as a potential barrier to participation? Can equal access of all participants be guaranteed?

- Is safety guaranteed for all participants after disclosure of their gender identity?

- Whose gender is being assessed in the study? Only those of the participants or also that of the provider/investigator?

Analysis	• If multiple instruments will be used to determine different dimensions of gender (identity, roles, relations), how will these results be weighted in analysis? Will variables be nominal or continuous?
	• How will the interaction between sex and gender be captured?
	• In analysis, which techniques will be used to account for intersectional factors?
	• Has a power analysis been conducted? Can sufficient outcomes be expected for all participants: women, men and gender-diverse participants?
	• How will a low number of gender-diverse participants affect the analysis? Will they be treated as outliers or can their data be meaningfully included for future meta-analysis?
	• Do qualitative analyses consider gendered language, gendered interactions and gendered themes?
Reporting	• Does the publishing medium have specific requirements for reporting gender?
	• Is the methodology described in enough detail to allow for reproduction?
	• Have the SAGER guidelines been applied?
	• Have null findings been included?

Related new case studies

▶ Chronic pain

▶ COVID-19

▶ Prescription drugs

Related previous case studies

▶ Colorectal cancer

▶ Dietary assessment method

▶ Heart disease in diverse populations

▶ Nutrigenomics

▶ Osteoporosis research in men

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ANALYSING SEX IN TISSUES AND CELLS

In 2001, the US Institute of Medicine declared that 'every cell has a sex' (Pardue et al., 2001). Progress has been made over the last two decades in understanding how to analyse sex in tissues and cells (Ritz et al., 2014; Shah et al., 2014; Clayton, 2016; Tannenbaum et al., 2016; Docherty et al., 2019).

General points

▶ Not every experiment needs to be designed to evaluate sex differences. However, for every experiment, the sex of the tissues or cells needs to be noted and reported in order to ensure that experiments are reproducible and that findings (in one sex) are not overgeneralised (to the other sex) (Wizemann, 2012).

▶ It is important to consider whether or not the expression of genes (on the sex chromosomes or autosomes) of a cell or tissue under study is influenced by sex hormones. The expression of genes may be influenced by sex steroidal hormones in the cell culture media or by the hormonal environment of the donor animal (Veilleux and Tchernof, 2012). Cells removed for *in vitro* experiments may behave differently than *in vivo*. Cell media may influence cell behaviour. For example, phenol red, a common pH indicator, is oestrogenic and as such it can alter cell responses (Mauvais-Jarvis et al., 2017).

▶ Consider the basic question to be addressed and how the study design and outcomes might be affected by the sex of tissues and cells. Sex differences must be considered before they can be ruled out.

Identify problems and formulate hypotheses

▶ Distinguish between sex (biological) and gender (sociocultural). Sex is genetically intrinsic to every cell of a sexually reproducing organism. In human tissues, gender can influence tissue and cell experiments in many ways, even though tissues and cells are not themselves gendered. For instance, gender influences research priorities, research designs, and the development of cells and tissues before they are removed from a donor. In studies of bone tissue, for example, bone development is influenced by biological sex (in part through the action of sex steroid hormones) but also by gender (by diet and patterns of physical activity).

▶ 'Sex' and 'gender' are frequently and incorrectly used interchangeably in the literature. Therefore, perform a literature and database search with adequate terms for 'sex' and 'gender'. MeSH (Medical Subject Headings), the US National Library of Medicine controlled vocabulary thesaurus used for indexing articles for PubMed, does not distinguish consistently between sex and gender (in large part because authors do not). Hence, researchers need to develop search strategies to identify the full range of previously documented sex and gender differences. In life sciences research, it may be necessary to use search terms such as 'female', 'male', 'sex steroid hormones', 'gonadal hormones', 'sex chromosomes', 'oestrogens', 'androgens' and 'steroid receptors'.

▶ Several studies suggest combining the name of a condition or biomedical research topic with standardised MeSH terms, such as 'sex factors' and 'sex characteristics' or other terms such as 'gender differences' and 'sex differences'. Researchers have developed search strategies that yield better results than 'sex' or 'gender' alone (Moerman et al., 2009; Oertelt-Prigione et al., 2010).

Research design

▶ Determine how a given experiment will use sex as a biological variable. This decision can be based on prior sex-specific research or assumptions about biological plausibility.

▶ Cells and cell lines can be selected for study in different ways depending on the types of questions to be asked (see Table 1).

Table 1. Configuring biological experiments on cell lines and tissue samples

Cell lines and/or tissue samples	Study characteristics and considerations
Cells and tissues from female and male donors	Cell lines of female or male cells will have different genetic characteristics and may exhibit differences in growth rate, metabolism and response to stimuli (Ritz, 2014). If sex is used as a variable, other donor characteristics should be matched or differences must be controlled for. Studies of both female and male cells give insight into specific forms of sexual dimorphism. Analysing other factors that may intersect with sex is critical in order to avoid overlooking sex differences as well as to avoid overemphasising sex.
Single sex	Studies in cells or tissues from only one sex (female or male) may be useful in closing research gaps, investigating differences among cell types within a sex, or studying diseases or interventions that are female-specific or male-specific. For example, female-only studies might be used to investigate how cells differ by hormonal status (pre-pubescent; pre-menopausal with normal ovulation; pre-menopausal with ovulation altered by hormonal contraceptives, drugs or stress; and menopausal), age, circadian cycle and other factors. Male-only cells or tissues may be useful in closing research gaps, investigating differences among cell types within a sex, or studying diseases or interventions that are male-specific (e.g. prostate cancer). Results in single-sex studies should not be generalised to the general population.

Collect data

▶ **Sample matching.** When sex is used as a variable, tissues and cells should be matched by non-sex characteristics that might influence outcome (such as age, hormonal status or the reproductive history of the donor). Alternatively, when such matching is not feasible, results can be disaggregated by sex and then adjusted depending on statistically significant differences between female-derived and male-derived tissues or cells by non-sex traits, presuming that such differences can be measured and their effects on outcome are known.

▶ **Cell media.** The expression of genes may be influenced by sex steroidal hormones in the cell culture media or by the hormonal environment of the donor animal (Veilleux and Tchernof, 2012). Cell media may

influence cell behaviour. For example, phenol red, a common pH indicator, is oestrogenic and as such it can alter cell responses (Mauvais-Jarvis et al., 2017).

Analyse data

▶ Analyse all concepts and theoretical models for unfounded assumptions (see 'Rethinking concepts and theories', Schiebinger et al., 2011–2020a).

▶ Studies should take care to avoid the following.

- Assuming that findings in one sex apply to the other.

- Mixing cultures of cells from female and male animals. Do not mix cultures of cells from female and male animals, as cells may have different rates of cell cycle and proliferation and may respond different to stimuli for apoptosis and growth factors added to the cell media. For example, female and male cells have different sensitivity to certain apoptotic agents, and these differences are modulated by cell type and age (Penaloza et al., 2009).

- Concluding that sex differences exist without accounting for confounding variables (see 'Intersectional approaches' above).

- Interpreting results in a sex-blind manner.

- Assuming that differences associated with sex also apply to gender.

Reporting results

▶ Report the sex of cells and tissues used in research, even in single-sex experiments (Wizemann, 2012).

▶ Report null findings. Researchers should report when sex differences (main or interaction effects) are not detected in their analyses in order to reduce publication bias, enable meta-analysis and promote the identification of confounding variables.

▶ Check that sex differences are properly visualised in the tables, figures, and conclusions (see 'Rethinking language and visual representations', Schiebinger et al., 2011–2020b).

▶ Check that sex-related findings are presented correctly in the title, abstract and keywords.

Disseminate

▶ If significant sex differences emerge, describe the follow-up research required.

▶ When sex differences are identified, specify how these findings might be translated into preventative, diagnostic and therapeutic practices to improve patient outcomes.

Related new case studies

▶ Prescription drugs

▶ Systems biology

Related previous case study

▶ Stem cells

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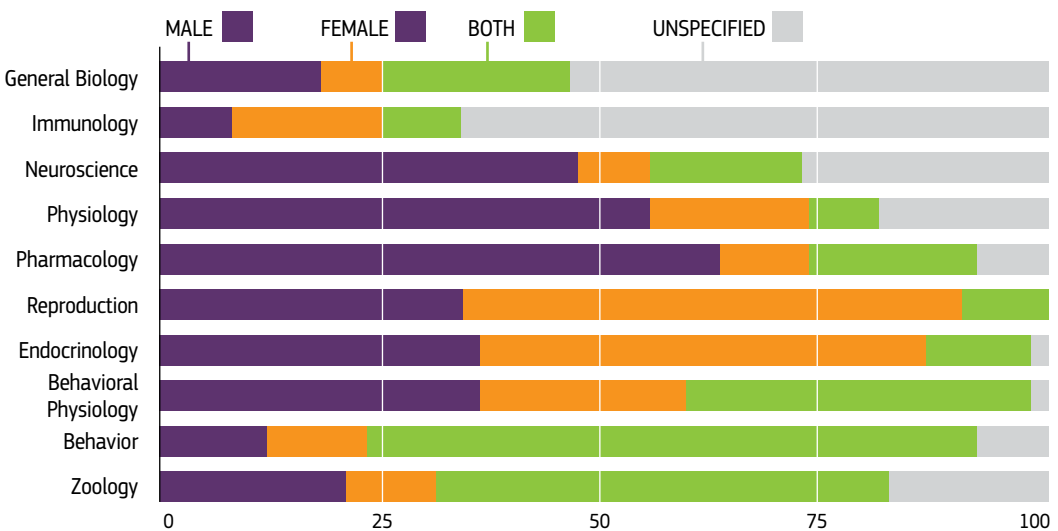
ANALYSING SEX IN LAB ANIMAL RESEARCH

Animal research has been vital to science and medicine since its inception. Until the 1960s, however, researchers rarely reported the sex of animals except in experiments related to reproduction. Even today, the sex of animal subjects is 'omitted in 22–42 % of articles in neuroscience, physiology, and interdisciplinary biology journals' (Beery and Zucker, 2011).

Analysis of animal studies in which sex is reported shows that females are underrepresented in most subfields except reproductive biology and immunology; see Figure 1.

Proportion of Research Studies Using Male and/or Female Animals

From published journal articles within specified biomedical subfield, 2009

Adapted from Beery et al., 2011

General points: the underrepresentation of female animals

Single-sex experiments are the only option for sex-specific phenomena (ovarian cancer or prostate cancer, for instance) and can also be beneficial if one sex has been understudied (McCarthy and Becker, 2002). The majority of single-sex animal experiments, however, do not fall into these categories. Female animals are generally underrepresented in studies of conditions that affect both sexes, and are also underrepresented in research where evidence suggests that sex influences outcomes.

When can experiments be done in only one sex?

▸ When studying a sex-specific phenomenon, such as ovarian cancer or prostate cancer.

▸ To address inadequate published data for one sex in a particular area.

▸ Where there is statistically robust evidence that sex does not influence a trait or outcome.
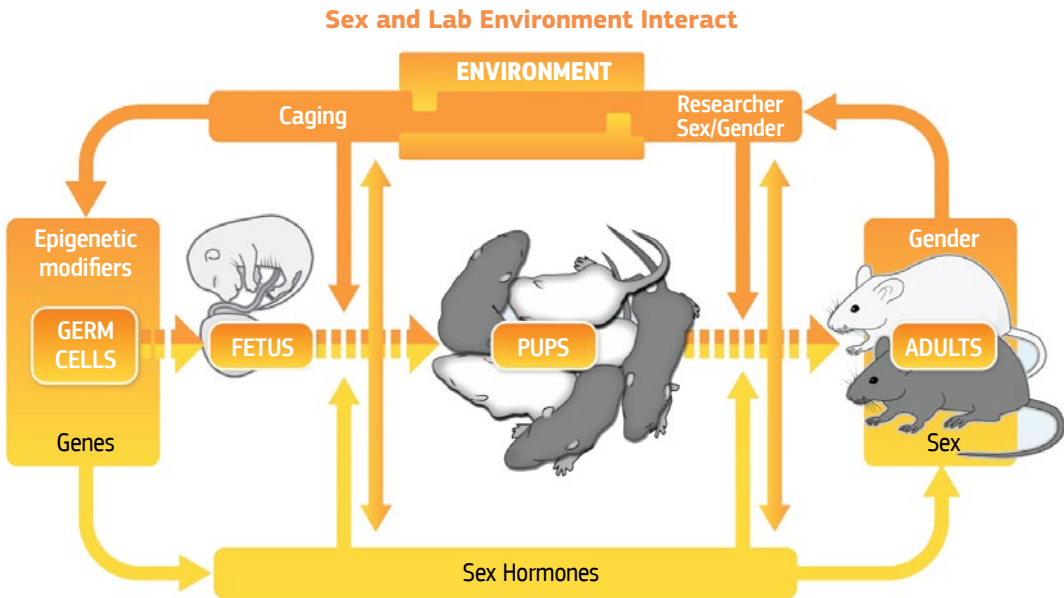
In diseases where one sex predominates, such as breast cancer, both sexes may still need to be included, but researchers may choose not

to use them in equal numbers. Things become more complicated in instances where a disease differs profoundly in women and men, but an animal model has been developed for only one sex. For instance, rodent models of hypertension do not accurately reflect the physiology of heart disease in women. In these instances, new models will need to be developed. It was discovered that patterns of disease differed in women where there was less occlusion of the coronary arteries but more microvascular disease due to changes in microvascular endothelial function (Miller et al., 2011; Regensteiner, 2015; Mehta, 2016; Ouyang et al., 2016). Animal models of coronary microvascular disease need to be established, including animal models that take into account potential interactions of pregnancy-related conditions such as preeclampsia or gestational hypertension, menopausal neurovascular dysregulation related to hot flushes, and metabolic conditions such as diabetes.

Sex and lab environment in animal studies

How can we best design animal studies to take into account sex (biological characteristics) and environmental factors and processes? Figure 2 shows the complex interdependency of sex and environment, including researcher sex, throughout the rodent life cycle.

Sex and Lab Environment Interact

Adapted from Regitz-Zagrosek, V. (2012). Sex and Gender Differences in Health. EMBO Reports. 13(7). 596–603.

Animal research includes the interaction between sex (biological characteristics, such as genes, hormones, age, reproductive phase and strain) and environmental conditions (such as caging practices, sex of researchers, attitudes and behaviours of researchers, room temperature and diet).

Research design

1. **Investigate the role of sex**

▶ The influence of sex must be investigated before it can be ruled out.

▶ Research can be done stepwise. Male and female animals should be strain-matched (or strain-matched and genotype-matched) and age-matched, and should be reared under identical conditions (cages, bedding, diet, etc.). Females should not be breeders unless required for assessment of the phenotype.

- **Step 1.** Total sample size (based on power calculations): including females and males in a study often requires doubling the number of experimental subjects, but not always. Efficient experimental designs can incorporate sex while maintaining control over variance (Beery, 2018). For example, factorial designs require sample sizes to be increased by 14–33 %, but not doubled (Miller et al., 2016; Buch et al., 2019). Analysing data by sex and environmental factors helps detect meaningful effects that, in turn, help reduce confounding variables and the cumulative number of experiments required.

- **Step 2.** Sex-based powering: test hypothesis in both males and females and power each to determine effect. Consider factorial designs to reduce sample size when investigating sex–treatment interactions in animals (Beery, 2018; Lazic, 2018).

- **Step 3.** Comparison between sexes: power studies to determine the actual 'sex effect'. Testing for sex effects has a financial cost. A demonstrated sex difference, however, justifies sex-specific research because harm in one sex is costly to society and individual patients. Overall, it is less expensive to understand sex in the basic science phase than during the more costly clinical trial phase (Klein et al., 2015). Analysing sex may decrease the number of drugs that fail in development and also helps companies avoid being forced to remove drugs from the market due to adverse events in one sex.

▶ Researchers should also evaluate overlap between groups (similarities between males and females) and difference within groups (differences among males or among females). Overemphasising sex differences should be avoided.

▶ Finding no sex effect should also be reported. To reduce publication bias, researchers should report when sex differences (main effects or interaction effects) are not detected or when data regarding sex differences are statistically inconclusive (Wizemann, 2012). Reporting null results is crucial for meta-analysis.

▶ For phenotypes that do not display sex difference, future experiments should be sex inclusive; that is, they should include equal numbers of randomly selected males and females for each test group studied. Not every experiment needs to be designed to evaluate sex differences. However, for every experiment, the sex of the animal test subjects should be reported to ensure that experiments are reproducible and findings in one sex are not overgeneralised to the other sex (Wizemann, 2012).

▶ Analyse the impact of sex hormones.

- **Considering the oestrous cycle** (Byers et al., 2012). Research has shown that the majority of sex effects are not influenced by cycle (Becker et al., 2005). Researchers should compare the variability in female and male responses. Researchers do not need to monitor the oestrus cycle

unless females are more variable. In a meta-analysis of nearly 10 000 traits, Prendergast et al. (2014) found that, for most biological measurements, females are no more variable than males (Becker et al., 2016; Itoh and Arnold, 2015). Other factors, including group versus single-animal housing, can have a greater impact on variability of a trait than stages of the oestrous cycle.

- **Menopause models.** Menopause is an emerging area of laboratory animal research. In rodents, reproductive aging occurs and can be used in research to gain insight into menopause in women. Reproductive aging in female rats or mice begins towards the end of the first year, and the timing can vary depending on strain and environmental factors (Finch et al., 1984). When over 1 year old, female rodents show low serum levels of gonadal steroids (persistent dioestrus) and/or chronically elevated serum oestrogen levels (persistent oestrus) (Finch et al., 1984). Persistent oestrus leads eventually to a dioestrous condition, but there can be an intervening period of pseudopregnancy, depending on the species (Finch et al., 1984). Ovariectomy can simulate reproductive aging by rapidly reducing gonadal steroid levels, and this 'acute menopause' has a multitude o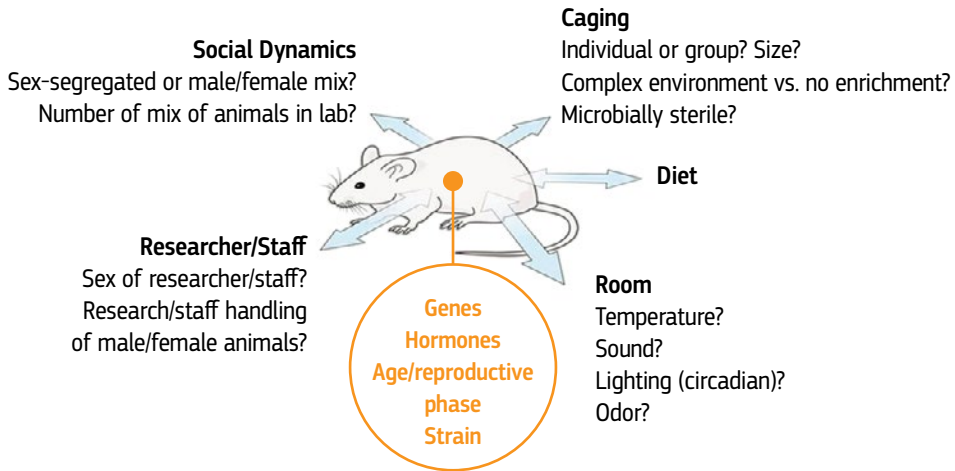f effects. One area of increasing interest is the effects of menopause on the immune system. In rodents, ovariectomy 'reduce[s] lymphocyte chemotaxis, mitogen-induced T cell proliferation responses, and [Interleukin-2] production' (Marriott and Huet-Hudson, 2006).

- **Pregnancy or pseudopregnancy.** Fewer than 10 % of medications approved by the US Food and Drug Administration since 1980 have enough information to determine risks of birth defects (Mishra and Mohanty, 2010; Adam et al., 2011). New animal research on drug safety should assess effects on the dam and the foetus during pregnancy and lactation (McDonnell-Dowling and Kelly, 2015).

- **Pharmacokinetics.** The oestrous cycle can also affect pharmacokinetics. For example, Kulkarni et al. (2012) found that the oral bioavailability of genistein, a soy isoflavone with antioxidant properties, was inversely correlated with oestrogen level (which regulates hepatic disposition of a drug).

2. **Investigate how the environment interacts with sex**

Environmental processes, such as caging practices or differential handling, may affect female and male animals differently. Researchers should not identify an effect as dependent on sex (or a biological trait) when, in fact, it depends on an environmental condition.

Sex and Lab Environment Interact

Social Dynamics
Sex-segregated or male/female mix?
Number of mix of animals in lab?

Caging
Individual or group? Size?
Complex environment vs. no enrichment?
Microbially sterile?

Diet

Researcher/Staff
Sex of researcher/staff?
Research/staff handling
of male/female animals?

**Genes
Hormones
Age/reproductive
phase
Strain**

Room
Temperature?
Sound?
Lighting (circadian)?
Odor?

Animal research includes the interaction between sex (biological characteristics, such as genes, hormones, age, reproductive phase, strain) and the lab environment (caging practices, attitudes and behaviours of researchers, room temperature, diet, etc.). The double-ended arrows represent interactions between sex and environment.
© Schiebinger et al., 2011–2020.

Environmental processes that may interact with sex

▸ **Caging: individual versus group?**

- To avoid aggressive behaviours, male rodents are often caged in small groups or alone. Rodents housed alone 'expend more energy maintaining body temperature, which can cause differences in parameters such as caloric intake, muscle activity, metabolic rate, fat distribution, or body size, with a plethora of potential downstream effects on bodily and cellular activity' (Ritz et al., 2014. p. 8). In contrast, females are more often housed together to lower costs. Rodents housed together often sleep clustered and, as a result, expend less energy to keep warm. In this scenario a sex difference may be identified where, in fact, differences result from different housing conditions.

- A same-sized group may create different stressors for females and males. Being caged alone may itself cause stress (Ritz et al., 2014), but single housing reduces trait variability in both males and females (Prendergast et al., 2014).

- Group caging can also result in self-induced or social hair loss, also called barbering (Kaleuff et al., 2006). Barbering (1) often reflects social hierarchies in same-sex group cages (both females and males); (2) may result from the stress of overcrowding; (3) takes place in breeding groups (females barber males); and (4) occurs among lactating rodents (pups barber mothers). Barbering occurs in some strains more than others.

- Cage size can limit animal behaviour. For example, many cages cannot accommodate the full range of female

sexual behaviour. In the wild, females may dart, approach and solicit males (Birke, 2011). For these reasons, articles should specify housing conditions.

▶ **Researcher/staff.** Experimenters may be a confounding variable in rodent research when stress is a significant factor. One study found that rats and mice demonstrated a reduced pain response in the presence of a male experimenter compared with a female experimenter. Both male and female rodents showed this response, but females showed it more. The researchers identified this 'male observer effect' as a stress response to androstenone and androstadienone, axillary secretions found in higher concentrations in males than in females. In addition to stress-induced analgesia, the presence of these compounds resulted in increased plasma corticosterone levels (Sorge et al., 2014).

▶ **Handling.** Control rodents should undergo similarly stressful procedures to those of the experimental rodents, such as sham surgeries. Taking vaginal smears to establish the stage of the oestrous cycle in female rodents can be stressful; male rodents should be handled in similar ways (Becker et al., 2005). Without these controls, differences in stress responses can be mistaken for other sex differences.

▶ **Circadian cycling.** Testosterone varies seasonally and with circadian rhythms. Similarly, hormone concentrations in females can fluctuate over the course of a single day of the oestrous cycle. Hypothalamo-pituitary-adrenal secretions, which in turn affect gonadal secretions, also vary over the course of the day (Becker et al., 2005). Researchers should specify the photoperiod in the colony and the time of day at which measurements are taken.

▶ **Social dynamics.** Edelmann et al. (2013) found that rat maternal behaviour mediates sex differences in play among juveniles. Simulated maternal grooming, in addition to normal maternal care, reduced play in males but not in females. This effect may be mediated by increased serotonin signalling, as maternal licking also increased serotonin receptor mRNA.

▶ **Temperature.** Laboratory mice are typically housed at temperatures below their thermoneutral zone. Gaskill et al. (2009) found that, when mice were able to move among three cages with different temperatures, mice of both sexes preferred warmer environments for inactive and maintenance behaviours (with no preference for active behaviours). Females preferred the highest temperature; males showed no preference between the medium and highest temperatures. As with day length, ambient temperatures in the research colony should be reported consistently.

▶ **Diet.** Diets affect weight, metabolism, hormone levels and immune functions; hence, diet formulation should be reported (Bhupathy et al., 2010; Luczak et al., 2011). Glover and Assinder (2006) found that diets rich in phytoestrogens may have sex-specific effects on cardiac health. In males, soy-based diets significantly decreased cardiac function, increased myocellular disarray and led to an increase in β-MyHC, a myosin motor protein associated with heart failure. This last effect was also observed to a lesser degree in females.

▶ **Bedding.** Bedding may also have an impact on hormonal status. Corncob bedding has been reported to reduce aggressive behaviour compared with cardboard-based bedding, by influencing oestrogen receptor alpha expression in the brain (Landeros et al., 2012). Elevated

levels of non-oestrogenic mitogens have also been previously reported in mice housed on corncob bedding (Markaverich et al., 2002).

Analysing sex and environment, and how they interact, is important to increase the translational value of animal models. The cost of developing a drug ranges between USD 350 million and USD 5 billion; 95 % of drug candidates fail (Arrowsmith, 2011; Herper, 2013; DiMasi et al., 2016). Including sex and gender as research variables may help bring down those costs,

promote discovery of disease mechanisms and save lives.

Related new case study

▶ Systems biology

Related previous case studies

▶ Animal Research

▶ Animal Research 2

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ANALYSING SEX IN BIOMEDICINE

Sex should be included in each step of the research process (Wizemann and Pardue, 2001; Beery and Zucker, 2011; IOM, 2012; Clayton, 2016; Tannenbaum et al., 2016).

Identify problem and formulate hypotheses

The first step towards excellent research is analysing sex as a biological variable. Sex has historically been ignored as an explanatory variable; hence, literature searches may underplay its importance. Nevertheless, the absence of pilot data should encourage, rather than discourage, analysing sex. Sex has already been linked to numerous biological and physiological sex differences and to specific health outcomes. Some resources for obtaining sex-specific literature are available online (Montgomery and Sherif, 2000; Moerman et al., 2009; Oertelt-Prigione et al., 2010; Stewart et al., 2014).

Sex is an essential variable to consider in developing scientific hypotheses. Questions to address when developing research hypotheses include the following. Should sex be considered a co-variate, a confounder or an explanatory variable? How will it be possible to identify potential sex differences without overstating them? What is the biological plausibility of sex emerging as an important variable in this research question? Which intersecting factors (see 'Intersectional approaches' above), such as age or hormonal status, should be considered?

Research design

Designing research requires consideration of the study type, study protocol and statistical requirements, as well as practical and logistical factors.

▶ **Study type.** What type of study is needed to address the specified research hypothesis? Options include cross-sectional or longitudinal studies, observational or interventional studies, and studies with controls or without. How might potential sex differences influence these choices? One aspect to consider in longitudinal studies is how reproductive history potentially influences the cohort and if this is appropriately controlled for. If women get pregnant during the study, does this affect the potential data acquisition? If the population is of perimenopausal age, is this being taken into consideration? Will this be documented to allow analysis? If the study is cross-sectional, do hormonal profiles play a role? When specific interventions are considered, will the populations be stratified by age and sex, and will equal distribution be ensured? Is oversampling of one group potentially warranted? If controls are being used, how are they selected? What are controls matched on?

▶ **Study protocol.** When developing the study protocol, potential sex-dependent aspects should be explicitly addressed. If hormones are going to be measured, will circadian rhythms be taken into account? Are the facilities set up to accommodate this? If metabolic differences are to be measured, will physiological sex differences be considered? Is there a contingency plan if sex differences make an intervention difficult? For example, if women's generally smaller vessels preclude some female participants from a vascular intervention, how will this affect data collection?

▶ **Statistical requirements.** The fundamental requirement for statistical analysis is an adequately large sample and an appropriate number of outcomes to guarantee power for the subsequent analysis. For sex-specific research this means including adequate numbers of female and male subjects. Including both sexes does not necessarily mean doubling

the group size overall, as factorial designs (progressing from a T-test to an analysis of variation) reduce the sample size increase from doubling to about a 50 % increase (Miller et al., 2017; Buch et al., 2019). In some cases, single-sex studies might be sufficient, e.g. if a condition affects only one sex (such as prostate cancer) or if a significant number of data has been collected in patients of one sex. In this case, collecting data from the other sex using the same protocol might be the most cost-effective option.

▸ **Practical and logistical factors.** Are samples of both sexes accessible? Commercially available fibroblasts tend to be male cells and many tumour cell lines are available only from the sex most affected. If a researcher wants to compare molecular patterns in breast cancer in females and males, it might be challenging to acquire samples for the latter. If patients are involved, will equal access to the study be guaranteed? Could potential differences in disease incidence limit participation or confound results?

Collect data

Sex-specific data should be collected for cells, animals and humans. Sex definition should be prespecified (see Section 2.1) and approaches to the inclusion of non-binary individuals should be considered (and specified).

▸ **Ascertaining the genetic make-up of all cells.** Analysing sex in cell samples requires obtaining reliable information about the cell's genetics. When the cell donor is known, this should be obvious. However, phenotype (at least in humans) does not automatically translate to XX or XY genetics (see Section 2.1) and may have to be confirmed. In addition, cell cultures frequently change their karyotype after years in culture, especially cancer cells (Duesberg et al., 1998).

This affects autosomes as well as sex chromosomes. Furthermore, techniques such as the reprogramming of cells into pluripotency affects the methylation of the chromosomes and can potentially alter the inactivation patterns of the X chromosome (Lessing and Lee, 2013). This can impact transcriptional profiles and should be considered.

▸ **Recording the sex of research participants.** This is a prerequisite for sex analysis. Some granting agencies and peer-reviewed journals require the reporting of sex for human, animal and (where appropriate) organ, tissue and cell research (see Chapter 5, 'Policy recommendations for Horizon Europe'; Schiebinger et al., 2011–2020a). Reporting the sex of the research subject is important even in single-sex studies, to allow meta-analysis, in order to identify research gaps and prevent overgeneralising findings beyond the sex studied. When including human subjects, attention should be paid to how researchers will ask about sex (see 'Asking about gender and sex in surveys' above). Will sex be conceptualised as binary? When working with very large datasets, the likelihood of including individuals with differences in sex development/intersex is very high, given that these individuals range from 1 in 100 to 1 in 4 500 in humans, depending on the criteria used (Huges et al., 2006; Arboleda et al., 2014; see also Section 2.1). In practice this means that some data will not fit into a prespecified binary sex classification. Researchers should define how they want to address this issue before data collection. Data from these individuals should not be simply labelled as outliers and disregarded. They should be handled in accordance with pre-planned protocols.

Analyse data

▶ **Analysing results by sex.** Sex-specific analyses should be conducted and the findings reported. Providing sex-disaggregated data facilitates future meta-analysis. Women and men, for example, may require different dosages of a drug to produce a given effect (see case study 'Prescription drugs'). Adjusting the data for baseline differences and factors that intersect with sex is a crucial step in understanding the sex differences observed. Researchers who analysed sex in studies of cardiovascular disease, for example, identified sex differences in arterial plaque formation: women tend to develop diffuse plaques, whereas men more often develop localised plaques (von Mering et al., 2004). This difference has ramifications for the design of stents (see case study 'Heart disease in diverse populations', Schiebinger et al., 2011–2020b). Nevertheless, researchers should also be aware that differences that exist within groups of females and males (or women and men) might be larger than differences between the groups. Both biological and sociocultural factors differ substantially between individuals over their lifetime and will shape the expression of many traits. These include profound changes associated with reproductive biology (e.g. at puberty and, in women, throughout the menstrual cycle, during pregnancy and at menopause), with transitioning from one sex to another and with ageing. Take, for example, height. On the whole, men are taller than women. Large within-group variations and differences between countries, however, complicate this sex difference. Many women are taller than many men. Researchers need to consider that limiting analysis to a comparison of means will potentially limit the real-world applicability of their results.

▶ **Collecting and reporting factors intersecting with sex.** Women, men and gender-diverse individuals differ by age, lifestyle (e.g. diet, physical activity, use of tobacco, alcohol or other drugs), socioeconomic status, and other gendered behaviours and variables. It is important to consider which of these might be relevant to the proposed research.

▶ **Sex as an explanatory variable or a confounder.** In many cases, sex will play a role in both explaining the results and acting as a potential modulator for other causal pathways. Nevertheless, most studies will allow only the description of correlation rather than causality. This should be taken into account when conducting the analysis and reporting results. Drawing a causal diagram could make the underlying assumptions explicit and sharpen the analysis.

Reporting and disseminating results

▶ **Formats for reporting.** Reporting should offer as much detail as possible about experimental design in order to support reproducibility. Researchers should consider following the SAGER guidelines (Heidari et al., 2016) for general publications and the PRISMA and CONSORT Equity guidelines (Welch et al., 2016, 2017) when reporting clinical trials. Rigorous reporting will increase the likelihood of reproducibility by other researchers.

▶ **Reporting null findings.** Researchers should report when sex differences (main or interaction effects) are not detected in their analyses, in order to reduce publication bias, an important consideration in meta-analyses (IOM, 2012). Where relevant, researchers should note when data regarding sex differences are statistically inconclusive, especially

in the context of factors intersecting with sex. Statistical power may be limited in cases where it is difficult to recruit patients of one sex, for example.

▶ **Choice of medium.** Most research will be published in peer-reviewed journals, and numerous journals support sex-disaggregated reporting and require a description of why and how sex (and sometimes gender) has been considered during the experimental process. In addition to the scientific media, social and general media should be considered to make results accessible to the general public and promote awareness of the modulating role of sex and gender.

Related new case studies

▶ Chronic pain

▶ COVID-19

▶ Prescription drugs

▶ Systems biology

Related previous case studies

▶ Colorectal cancer

▶ De-gendering the knee
Dietary assessment method

▶ Exploring markets for assistive technology for the elderly
Heart disease in diverse populations

▶ HIV microbicides

▶ Osteoporosis research in men

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Information and communication technologies

ANALYSING GENDER AND INTERSECTIONALITY IN MACHINE LEARNING

Machine Learning (ML) technologies, including risk scoring, recommender systems, speech and facial recognition, operate in societies alive with gender, race and other forms of structural oppression. ML systems can play a part in reinforcing these structures in various ways, ranging from human bias embedded in training data to conscious or unconscious choices in algorithm design. Understanding how gender, sex, ethnicity and other social factors operate in algorithms in particular contexts can help researchers make conscious and informed decisions about how their work impacts society.

1. **Analyse the social objectives and implications of the work**

Teams need to work together to define the objectives of the system being developed or researched and to evaluate its potential social impacts, guided by the following questions.

▶ How are the priorities and objectives of the technology set? Whom will it benefit, and who will be left out or put at risk (Gurses et al., 2018)?

▶ How do gender norms shape the research/product/service/system (Leavy, 2018)?

▶ How might structural racism shape the work, e.g. with racial stereotypes being reproduced in search algorithms (Crenshaw, 1991; Noble, 2018)?

▶ How do wealth disparities shape the work, e.g. will the system be deployed against or exclude those in poverty (Eubanks, 2018)?

▶ How does environmental sustainability shape the work, e.g. where training a deep learning model has a large carbon footprint (Strubell et al., 2019)?

2. **Analyse the data for potential biases**

Each training set should be accompanied by information on how data were collected and annotated. Data containing human information should include metadata summarising statistics on factors such as participant gender, sex, ethnicity, age and geographical location (Gebru et al., 2018). Data labelling done through crowdsourcing, such as MS Turk, should include information about crowd participants, along with the instructions given for labelling (Zou and Schiebinger, 2018).

▶ Do the data used to train and test the model embed human bias? See, for example, Buolamwini and Gebru (2018).

▶ Analyse the contexts in which the data were generated. What are the known gender biases and norms that may influence the data-generating process? See, for example, Shankar et al. (2017). Some features may have a different interpretation or impact when presented by members who use them to signal identification with a self-defining social group (e.g. the deliberate socially affirmative use of words that are considered offensive according to more generally prevailing social norms).

▶ It is also possible to introduce bias during the data preparation stage, which involves selecting which attributes you want the algorithm to consider. First, consider whether it is appropriate for an algorithm to use gender (e.g. if it will be used to advertise clothing, which is often gender-specific) or not (e.g. if it will be used to advertise jobs, which need to be equally visible to all genders). If inappropriate, consider removing explicit gender attributes. In addition, consider if any of the features selected for inclusion in the model are likely to be distributed unequally among different genders. For instance, if the model uses features that

might correlate with gender, such as occupation or single-parent status, it may still indirectly use gender.

▶ It is also possible to embed bias in the objective functions and/or the heuristics guiding search-based algorithms. For instance, using health costs as a proxy for health needs in the formulation of an objective function could lead to racial bias in cases where patients from one racial group have less money allocated to them (Obermeyer et al., 2019).

▶ Do the training data cover a diverse enough sample of the population to ensure that any models trained on them will perform well throughout populations? Are your data balanced for gender, ethnicity, geographical location, age and other social factors?

3. Analyse model for fairness

▶ Have you formulated an appropriate definition of fairness and tested the ML model against it?

Where an ML model will be used to determine significant outcomes for people, and where legal constraints or socially agreed norms are clear, it may be appropriate to formulate a quantifiable measure of fairness. This can be used to test the model itself and detect whether or not its outputs might have an unfair disparate impact by gender (Dwork et al., 2012; Hardt et al., 2016; Corbett-Davies et al., 2017). NB: even a system that is fair according to such measures can still be used in unjust ways if it is deployed on an already marginalised and oppressed population.

▶ Pay attention to intersectionality when assessing potentially discriminatory ML models.

Some measures of fairness involve testing how the model performs on a limited set of protected characteristics (e.g. gender, race) in isolation; however, this could miss intersectional forms of discrimination, where people are at the intersection of two or more forms of discrimination (e.g. black women, elderly Asian men). Alterna-

tive measures aim to ensure that the algorithm achieves good performance not just in aggregate but also for each of the subpopulations, which could be more granular (Kim et al., 2019; Tannenbaum et al., 2019).

▶ Use the fairness definition to constrain or retrain your ML system.

Having established a fairness definition, use this to audit an existing system or to constrain the development of a new one, so that it conforms to the definition. Various approaches can be used to preprocess the data to mitigate biases in the model, to constrain the learning algorithm or to modify the model after training. Which of these is most practical will depend on context (Bellamy et al., 2018).

▶ Have you considered how the model, once deployed, might interact with the broader sociotechnological systems in gendered ways?

A model designed, for instance, to predict the optimal bid for advertising space in a personalised auction might appear to be gender-neutral in testing. When, however, that system is deployed against competitors who are targeting by gender, the supposed gender-neutral system may end up placing advertisements in a gender-biased way (Lambrecht and Tucker, 2019). If the outputs are used to guide human decision-making, potential biases of the decision-makers might cancel out or overcompensate any de-biasing measures applied to the ML model.

4. Subcategories of machine learning

While the considerations above are widely applicable, de-biasing approaches will be different depending on the subtype of machine learning in question. The following is a non-comprehensive list of subcategories in which different methods may be needed.

▶ **Natural language processing**

- Researchers have proposed ways to analyse and identify gender biases in computational models of language, in particular in word embeddings. Geometry-based techniques allow the comparison of

the embedding of masculine or feminine words in relation to other words in a language. These approaches also enable such embeddings to be de-biased, e.g. such that 'babysitter' would be equally close to 'grandfather' as to 'grandmother' (Bolukbasi et al., 2016). Other researchers applied the standard implicit association test to word embeddings to demonstrate that they contain many human-like biases (Caliskan et al., 2017). Still others have developed a gender-neutral variant of GloVe, an unsupervised learning algorithm for obtaining vector representations for words (Zhao et al., 2018). For images, researchers first showed that training algorithms can amplify biases present in the training data and then developed a technique to reduce this amplification (Zhao et al., 2017).

- Similar techniques can also be used to study historical stereotypes and biases in society at large. Researchers used geometry-based metrics for word embeddings trained on text data over 100 years to identify changes in historical gender and ethnic biases (Garg et al., 2018). Similar methods may be used to compare biases in texts today.

▶ **Ranking and recommender systems**

- Fairness in ranking deals with situations in which a set of people or items need to be ranked (e.g. candidates for a job interview, or book recommendations) in a fair way. Because measures of quality or relevance might be biased against some (e.g. female candidates or authors) the top-ranked candidates or books might be disproportionately relevant to others (e.g. men). Computational approaches to fair ranking aim to enforce ranked group fairness on these search results or recommendations (e.g. Zehlike et al., 2017).

▶ **Speech recognition**

- Current speech recognition suffers from similar challenges to those of computer vision (Tatman, 2017); similar care in collecting representative datasets should be applied.

▶ **Facial recognition**

- NIST's 2019 report on evaluating commercial face recognition services found that 'black females … is the demographic with the highest FMR (false match rate)' (NIST, 2019).

Related new case studies

▶ Extended virtual reality

▶ Facial recognition

▶ Virtual assistants

Related previous case studies

▶ Machine learning

▶ Machine translation

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ANALYSING GENDER AND INTERSECTIONALITY IN SOCIAL ROBOTICS

Can social robots be gendered? Do users gender robots even when designers intend to create gender-neutral devices (Nass and Moon, 2000)? Understanding how robots are gendered can help researchers, designers and users make conscious decisions about what features to look for in a robot and how robots and chatbots might enhance social equality, or at least not hinder it (see Gendered Innovations 1 case study 'Gendering social robots', Schiebinger et al., 2011–2020).

1. **Consider gender in user perspectives**

How are users engaged the product lifecycle, from planning to consumption?

▶ Have you included a wide and representative variety of users of different genders/sexes, ethnicities, ages, socioeconomic statuses, heights, (dis) abilities, body sizes, etc., and have you considered the intersection between these attributes? User configuration will depend on the product you envisage (Rohracher, 2005; see also case study 'Facial recognition').

▶ Is your product designed to fit users with different body types, e.g. short women and tall men? Envisaged user height and weight may have sex implications for many technologies, such as exoskeletons (Odah et al., 2018; Søraa and Fosch-Villatonga, 2020).

▶ Might different groups of potential consumers (e.g. women, men, gender-diverse people) have different expectations, needs or motivations when it comes to acquiring the technology, or concerns about the human–robot interface (Beraldo et al., 2018)?

▶ Is there a risk of excluding certain users, e.g. those with disabilities or of low socioeconomic status, through the design of the technology (Tay et al., 2014)?

▶ Do any robot features reinforce existing gender inequalities, gender norms or gender stereotypes (see case study 'Virtual assistants and chatbots')?

▶ Do any robot features reinforce existing social roles (e.g. gender segregation in the workforce, such as men being associated with engineering and women with domestic technologies) (see Schiebinger et al., 2011–2020)?

2. **Is your robot designed to promote social equality?**

Roboticists have the opportunity to challenge gender stereotypes in ways that can lead users to rethink gender norms.

▶ Does your robot reproduce existing gender stereotypes, norms, roles and assumptions? What is the impact on social equality? (see Gendered Innovations 1 case studies 'Gendering social robots', 'Haptic technology' and 'Machine translation', Schiebinger et al., 2011–2020a, 2011–2020b, 2011–2020c)

▶ Can you build choice into your robot so that users can choose male, female or gender-diverse features (Reich-Stiebert and Eyssel, 2017; see also case study 'Virtual assistants and chatbots)?

3. **What features elicit gender attribution in robots?**

These practices could lead to gendered robots:

▶ choosing a male or female name to label the robot (Crowell et al., 2009; Alexander et al., 2014; Kuchenbrandt et al., 2014; Tay et al., 2014; Reich-Stiebert and Eyssel, 2017; Kraus et al., 2018);

▶ colour-coding the robot (Powers et al., 2005; Jung et al., 2016);

▶ manipulating visual indicators of gender (for example, face, hairstyle or lip colour)

(Powers et al., 2005; Eyssel and Hegel, 2012);

▶ using a low-pitched or high-pitched voice (Powers et al., 2005; Crowell et al., 2009; Siegel et al., 2009; Eyssel et al., 2012; Alexander et al., 2014; Kuchenbrandt et al., 2014; Tay et al., 2014; Reich-Stiebert and Eyssel, 2017; Kraus et al., 2018);

▶ designing a gendered personality (Kittmann et al., 2015; Kraus et al., 2018);

▶ deploying robots in gender-stereotypical domains, such as a male-voiced robot for security and a female-voiced robot in a healthcare role (Eyssel and Hegel, 2012).

Other aspects that may gender a robot, such as movement or gesture, still require empirical research (Alesich and Rigby, 2017; Søraa, 2017).

4. **Consider gender in human–machine interaction**

Test the interaction between human participants' sex/gender and robot 'gender'. Test with differently gendered parameters, if relevant (Powers et al., 2005; Jung et al., 2016; Nomura 2017).

▶ How do the sex and gender of humans and robots affect human–robot interaction, emotion, cognition and behaviour? How might these interactions be gendered?

5. **Consider the robot's sociocultural context**

When designing a robot for a global audience, consider socially and culturally specific aspects of sex/gender (and robots) as these play out in different parts of the world.

▶ Consider the impact of the social context or domain (healthcare, education, security, home, etc.) within which the human–robot interaction takes place (Bartneck et al., 2007).

▶ Consider the culture, region and country in which the robot will be implemented. What are the gender norms in that region? What assumptions might the culture have regarding robot–human interaction (Fraune et al., 2015)?

▶ Consider the social relations and intersectionality of the individuals in the contexts in which the robots are placed (e.g. would robots inherit racial bias? Bartneck et al., 2018).

Related new case study

▶ Virtual assistants and chatbots

Related previous case studies

▶ Gendering social robots

▶ Haptic technology

▶ Machine translation

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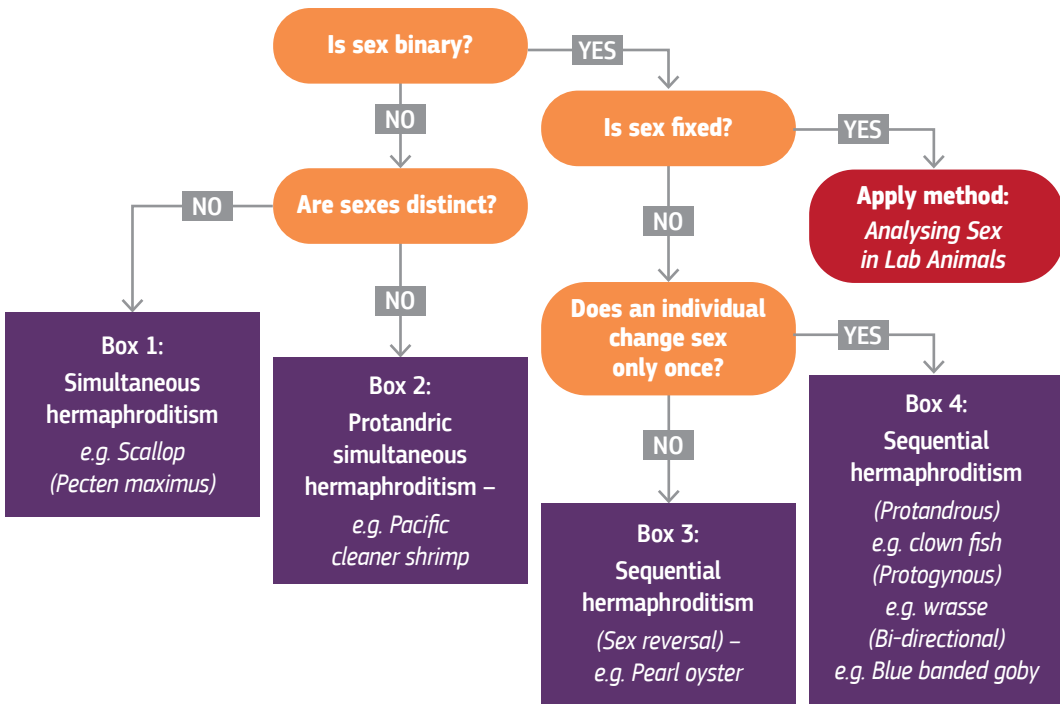
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Climate change

ANALYSING SEX IN HERMAPHRODITIC SPECIES

Sex analysis in species where hermaphroditism occurs will follow the same methodological processes as required for analysing sex in lab animals. However, when sex is not binary and stable, analysing the influence of sex on an individual's response to environmental stress is more complex. Such considerations require an understanding of sex differentiation, as well as the timing, direction and drivers of any sex change process.

Researchers need to account for hermaphrodites in their research design and analysis. The category of hermaphrodites may require further refinement, depending on how the species or individual under investigation allocates its resources to each sex, and how this changes over time. Researchers may need to adopt a fluid categorisation of sex, defined along a continuum and dependent on multiple interacting physiological, biochemical, behavioural and genetic process.

Decision tree. © Robert P. Ellis
Decision tree. © Robert P. Ellis

Box 1 – Simultaneous hermaphrodites contain both male and female gametes in the same adult at the same time. A familiar example is the king scallop, *Pecten maximus*, in which the bi-coloration of the roe results from oocytes (orange tissue) and spermatozoa (cream tissue) (Paz et al., 2005). In simultaneous hermaphrodites, the proportion of reproductive investment allocated to gametes of each sex can change during an individual's life (Janicke et al., 2013; Leonard, 2013); thus the impact of sex on whole organism energetics will depend on the balance of male and female tissue within an individual. Sex analysis with simultaneous hermaphrodites must consider the proportion of tissues with defined sex within an individual, in addition to how tissue sex determines the response of the whole organism.

King scallop (Pecten maximus). Bi-coloured roe indicates female (orange) and male (cream) gametes. Image rights CC0 1.0 Universal

Box 2 – Pacific cleaner shrimp are protandric simultaneous hermaphrodites; they develop as males and later change sex to simultaneous hermaphrodites (Fiedler et al., 2010). Following sex change, individuals have both male and female tissues in their gonads and produce both gametes. Sex analysis in such organisms must include the impact of sex change processes on the organism's response to environmental stress. To understand how the response of males and hermaphrodites differs when exposed to stress, researchers must account for the impact of male and female tissues, gametes and cellular processes within hermaphrodites, and how these interact within the whole organism. In addition, as with all simultaneous hermaphrodites, the comparison should account for the energy reserves and tissue volume an individual allocates to the production of each sex tissue proportionally (Janicke et al., 2013; Leonard, 2013), where possible (i.e. how female are simultaneous hermaphrodites?).

Pacific cleaner shrimp (Lysmata amboinensis) are protandric simultaneous hermaphrodites. They mature as male and later change sex to hermaphrodite. Source: Lonnie Huffman (https://creativecommons.org/licenses/by/3.0/deed.en)

Sequentially hermaphroditic fish.
A) Protandric hermaphrodite Red Sea anemone fish (Amphiprion bicinctus).
   Source: Mal B
   https://creativecommons.org/licenses/by-nd/2.0/
B) Protogynous hermaphrodite bluehead wrasse (Thalassoma bifasciatum).
   Source: Kevin Bryant
   https://creativecommons.org/licenses/by-nc-sa/2.0/
C) Bi-directional hermaphrodite bluebanded goby (Lythrypnus dalli).
   Source: Richard Ling
   https://creativecommons.org/licenses/by-nc-nd/2.0/

Box 3 – Pearl oysters develop primarily as male and later change to female (Adzigbli et al., 2019). However, sex reversal can subsequently occur as a result of environmental conditions, with the sex ratio linked to season (Southgate and Lucas, 2011). Moreover, in this species, the production and quality of pearls (Adzigbli et al., 2019), and thus the economic value of the species, depend on sex. Males produce higher-quality pearls. Sex analysis in species such as the pearl oyster, in which multiple sex reversals are possible, must investigate sex-determining mechanisms and how changing sex, possibly multiple times, affects an individual's performance, such as pearl production, growth or sexual reproduction.

Box 4 – Sequential hermaphroditism can be protandric (male to female), as in the case of clownfish (Casas et al., 2016); protogynous (female to male), as exhibited in wrasse species (Munday et al., 2006); or bi-directional (sex reversal in one direction irrespective of initial sex), as demonstrated in bluebanded gobies (Rodgers et al., 2007). While sexes are distinct and, following sex change, individuals become fully functional as the opposite sex, the sex change process within an individual occurs over multiple time frames (Lamm et al., 2015). In bluehead wrasse, the removal of the dominant terminal male from a reef induces large females to change sex. However, while the behaviour of this female changes to that typical of a male within minutes, gonadal sex change occurs over 1 to 2 weeks (Lamm et al., 2015). An area yet to be explored with respect to sex analysis and climate change is how an individual will respond to stress during this sex change process.

Related new case study

▸ Marine science

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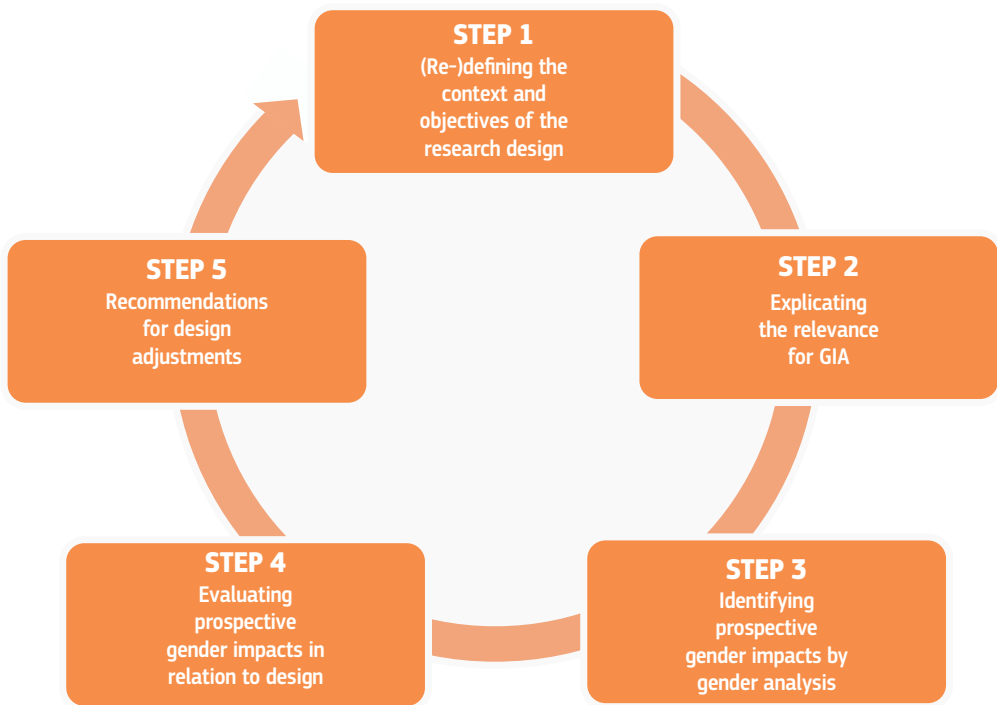Southgate, P. and Lucas, J. (eds.) (2011), *The Pearl Oyster*, Elsevier, Oxford.

Urban planning/transportation

GENDER IMPACT ASSESSMENT

GIA is a stepwise process (see diagram) designed to evaluate the potential impacts of research before research decisions are finalised. The goal is for experts to provide evidence-based recommendations for research redesign in the development phase. By employing the methods 'Analysing gender' and 'Intersectional approaches', experts can assess (1) the research objectives and priorities set (who, and what contexts and knowledges, may potentially have been overlooked in research design), (2) the research conceptional frameworks and analytical methods that may unconsciously exclude gender considerations and (3) the research questions that were formulated with specific focuses that may exclude particular populations.

GIA is a technique increasingly used in line with the principles of responsible research innovation and in support of the UN SDGs. It is particularly relevant to fields of R & D that rely on technological and networked infrastructure, and depend on adaption, such as in transport, urban planning, energy, mining, hydropower and agriculture (e.g. Spitzner and Buchmüller, 2016; Hill et al., 2017a,b; Graef et al., 2018; Peletz and Hanna, 2019).

The five steps for GIA, based on Spitzner and Buchmüller (2016) and EIGE (2017) and including critical reflections of Bacchi (2010) and Verloo (2005), are detailed below.

STEP 1
(Re-)defining the context and objectives of the research design

STEP 2
Explicating the relevance for GIA

STEP 3
Identifying prospective gender impacts by gender analysis

STEP 4
Evaluating prospective gender impacts in relation to design

STEP 5
Recommendations for design adjustments

The GIA five-step process to consider before finalising research decisions. Source: based on EIGE (2017)

Step 1: (Re-)defining the context and objectives of the research design

▶ What is the identified problem to be solved?

▶ Why is it important?

▶ What is the purpose of this R & D project?

▶ How is it defined/framed in societal terms?

▶ What gender and other (in)equalities are explicitly addressed?

▶ Which indicators are included for tracking and monitoring gender and other (in)equalities?

Step 2: Explicating relevance for GIA

Identify the gender dynamics at stake, either those already included or those that should be included. Consider:

▶ direct gender impacts, i.e. access to resources, such as funding, jobs, etc.;

▶ indirect gender impacts, i.e. access to resources via services, institutions, structures, etc.

Step 3: Identifying prospective gender impacts by gender analysis

What is the current state of affairs?

1. How do these affect the lives of women, men and gender-diverse individuals?

2. How do these affect knowledge? In other words, what gender biases are embedded in the knowledge base? For example:

   • do the research questions represent perspectives of different genders;

   • how are expectations, needs, and barriers framed by gender;

   • are key terms, categorisations, assumptions, concepts, frameworks and methods adequate to generate knowledge without implicit gender bias?

3. What societal gender equality issues are at stake? How are inequalities, including their roots in norms and values, addressed and how will equality be ensured? Consider:

   • representation and participation;

   • access to and control of resources;

   • gendered mechanisms, routines and structures;

   • gender-based societal norms and valuations;

   • gender stereotyping and static representations.

Symbolic order – gender-hierarchic constructions and positioning

▶ Does the research design support gender identities equally or does it value some over others in terms of societal, economic and political privilege?

▶ Does it create or reinforce symbols and narratives supporting gender equality?

Societal goals as supportive of the UN SGDs

▶ Does the research design address possible social, cultural, political and economic consequences?

▶ Which groups are addressed, and how are their roles, responsibilities and participation opportunities affected?

▶ Does the research design expand beyond what is commonly considered important or a concern to specific groups? Are these examined on an equal footing?

▶ Does the research design support redistribution of a gender-biased allocation of duties or rights, such as housework or land inheritance?

Access and control of resources and public infrastructure systems

▶ Does the research design lead to equal use of and access to resources, public space, public infrastructures and public budgeting?

▶ Are the interests and priorities of women, gender-diverse individuals and underrepresented minorities taken into account?

▶ Institutional framing and definitions of power

▶ Does the research design privilege specific points of view as the norm?

▶ Does it support generalisations claiming to be 'representative', 'natural', 'objective' or 'of general usefulness'?

▶ Does it contribute to gender-responsive subject- and field-specific knowledge bases?

Representation and participation

▶ Does the research design lead to more agency for underrepresented groups as well as equal and balanced representation in the fields addressed?

▶ Does it support gender-balanced (and underprivileged groups') representation in the planning and decision-making process?

▶ Does it increase the integration of societal issues important to their lives?

Violation of integrity borders

▶ Does the research design contribute to reducing harassment in all genders or underprivileged groups?

▶ Does it contribute to making safety and inclusivity the object of public infrastructure systems or private problem solving?

▶ Does it contribute to the safety for all people and relief of threats, restrictions, and sanctions?

Step 4: Evaluating prospective gender impacts in relation to design

Seek to evaluate overall gender impacts.

▶ What harmful, reinforcing, or transforming impacts on gender norms, gender identities and gender relations are foreseen?

▶ Which aspects reinforce or reduce inequalities and which ones promote equality in comparison to the existing situation?

Step 5: Recommendations for design adjustments

Experts should provide data-driven recommendations:

▶ to suggest a framework for how the research project can better reduce gender inequalities and promote social equality;

▶ to revisit the foreseen negative impacts and develop strategies to turn these into positive impacts.

Related new case studies

▶ Agriculture

▶ Quality urban spaces

Related previous case study

▶ Housing and neighborhood design

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Innovation

NORM-CRITICAL INNOVATION

Defining the problem and need

Do women and men have different perceptions, priorities and needs?

Make sure both women and men have the same influence in defining the problem that needs a new solution. This may require a specific focus on the previously underrepresented group.

One example is Volvo's Your concept car (YCC), which was designed by a team composed entirely of women. The YCC resulted in 50 new solutions, and several were technically forward-looking. The concept car clearly showed that cars usually are designed by men for men. The All Aboard concept boat is a similar project in the boat industry. This involved the design of a boat with user-driven solutions that took into account the needs of women on board pleasure boats. The intention with the YCC and the All Aboard concept boat was to highlight neglected needs and target groups that had not previously been prioritised in the design of cars or boats.

Another example is the Bang & Olufsen (B & O) Beosound 5 product, which was researched within the female innovation study led by the Danish firm design-people. Female-focused user research showed that the communication around the product highlighted benefits for men, and the product itself felt complicated to operate for women and stole too much of people's attention when installed in a living room. Following the study, B & O modified its communication and products to better reflect women's preferences (design-people, n.d.).

Norm-critical (or intersectional) analysis

When we do not see the norm or do not emphasise others' experiences, solutions risk strengthening stereotypes and limiting, hindering or even discriminating against others (Börjesson et al., 2016).

Norm-critical analysis questions norms, roles, power relationships and power structures that can be linked to different kinds of discrimination, and reveals who or what is or are included or excluded

by implementing various norms. Understanding norms also helps us to relate to underrepresented groups and understand their day-to-day experiences that shape their motivations and attitudes towards a product or service (Vinnova, 2018).

For example, when analysing health-related products and services, it is important to understand how women experience the healthcare system differently from men: among other things, they are more engaged with the healthcare system, go through more procedures that involve physical exposure and are more likely to have their physical complaints dismissed as emotional.

Norm-creative ideation

When generating ideas it is important to engage in a user-driven method whereby ideas are generated by the end-users. Include diverse group of end-users in order to ensure inclusive solutions. Using representative personas is a good methodology to relate to and empathise with diverse groups of users, which leads to user-centric ideas. The ideation phase is the most creative phase in an innovation process. Often, however, end-users are engaged in the test phase, when it is already too late to ensure that their ideas are considered for the project. Prototyping and testing are narrower in scope than ideation.

It is also important to try different solutions to a problem. This is done in the norm-creative phase, when norm-creative tactics, and various stances and procedures, are used to work towards that objective. The tactics illustrate various action paths, such as correcting social norms of exclusion by addressing the specific needs of marginalised groups through the design outcome. Another tactic might be to neutralise social norms of exclusion by creating flexible solutions that can be expanded, transformed or otherwise reconfigured by the users themselves.

Figure 1 features different tactics that can reframe a problem and lead to innovative outputs (Wikberg Nilsson and Jahnke, 2018).

From radical, through inclusive, to social tactics …

1. The Hole Punch
Addresses social norms of exclusion by influencing public opinion and increasing awareness through communicating/storytelling of negative user experiences.

2. The Sledgehammer
Opposes social norms of exclusion by performing user experiences of marginalization, exclusion, or discrimination.

3. The Plastering Trowel
Counteracts social norms of exclusion by creating solutions that fit and work for as many user groups' needs and preferences as possible.

4. The Precision Screwdriver
Corrects social norms of exclusion by addressing the specific needs of marginalized groups through the design outcome.

5. The Twirl Whisk
Thwarts social norms of exclusion by tweaking the problematic issue into a new form or function.

6. The Camouflage Net
Outsmarts social norms of exclusion by packaging the new in familiar and recognizable ways.

7. The Adjustable Wrench
Neutralizes social norms of exclusion by creating flexible solutions that can be expanded, transformed, or otherwise reconfigured by the users themselves.

8. The Welding Torch
Annuls social norms of exclusion by creating collective and shared systems or service solutions.

9. The Lever Bar
Challenges social norms of exclusion by building on affirmative actions and reversed privileges for marginalized groups.

10. The Eraser
Counteracts social norms of exclusion by obliterating "bad designs"·and starting from scratch.

11. The Grater
Works against social norms of exclusion by creating objects that challenges exclusion through their form and/ or function.

12. The Garden Trowel
Opposes social norms of exclusion by creating solutions that transcends norms and categorizations.

From readical, through inclusive, to social tactics.
Source: Wikberg Nilsson and Jahnke (2020), with permission

Prototyping/testing

Prototyping and testing are preferably done in real-life situations rather than in a lab. End-users should be engaged in this phase in order to reveal deeper insight and more valuable experiences.

For example, new technologies such as VR have been found to make women sick twice as often as men. Symptoms may be due to conflict between the body's visual and vestibular (inner ear) systems, resulting in greater sensitivity in women (Al Zayer et al., 2019; see case study 'Extended virtual reality'). Regulating the field of view in the navigation might be necessary to mitigate the visual/vestibular conflict, and prototyping this should be done in collaboration with women users.

Implementation

There may be differences in how women and men have access to solutions/innovations due to differences in income, access to technology, income differences, etc. All of these require gender analysis and the involvement of both women and men in the implementation phase.

Scaling up

It is important to analyse and identify key gender barriers to the scale-up phase. Scaling up an idea and attracting the market is not gender neutral.

For example, bias in VC decisions more often lead to underfinancing of women's ideas (see case study 'Venture funding'). However, crowdfunding has been found to be more gender neutral than other financial instruments needed to scale up. Research on venture capital financing has found that female-led companies receive substantially less venture capital financing than men and are also often expected to give up a greater proportion of ownership when receiving private funding. On the other hand, crowdfunding has been found to have a funding advantage for women, since they are perceived to be more trustworthy, an important criterion in crowdfunding (Gorbatai and Nelson, 2015; Johnson et al., 2018).

Failing to take into account gender factors can limit the reach and scale of innovation. A systematic approach to ensuring gender awareness in scale-up processes could significantly improve the effectiveness (Grand Challenges Canada, n.d.).

Related new case studies

▶ Smart energy solutions

▶ Extended virtual reality

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Integrating sex and gender analysis into research and innovation adds value to research and increases its societal relevance. It is thereby crucial to secure Europe's leadership in science and technology, and support its inclusive growth. To further strengthen the integration of sex and gender analysis into research and innovation, the European Commission convened an Expert Group to support these efforts.

This report highlights the results of the Expert Group and contains definitions of terms and methods relating to sex, gender and intersectional analysis, interdisciplinary case studies displaying how to integrate the gender dimension into various fields of research and innovation, as well as concrete policy recommendations. The material presented provides guidance for the Horizon Europe Framework Programme and seeks to contribute to the achievement of the UN SDGs.

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