Bringing the Benefits of Genome Sequencing to the World
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At Public Policy Projects, we believe that good public policy is the essential foundation of an open, liberal society.

Most public policy issues are complex and involve difficult choices and trade-offs. There is plenty of scope for honest disagreement about how to balance conflicting interests; it is the role of political leaders to make those choices and accept responsibility for the choices they make. But that system only works when political rhetoric is connected to reality and the programs which are presented to voters represent real options. If voters’ sense that the ideas are unrealistic, or that the implications have not been thought through, they conclude that the political class is at best self-serving and at worst corrupt.

Good public policy addresses the trade-offs and makes the choices explicit so that political leaders can be held to account for the implications of the choices they make.

This process requires an understanding of international context. In the age of the internet, Covid and climate change the list of issues which can be addressed at the purely national level is growing shorter all the time.

The mission of Public Policy Projects is to learn both from our own experience and from the experience of others and to make contributions to the policy debate which address real world choices based on real-world evidence.
This Global Insights report and programme of work were Chaired by Kate Orviss, Senior Adviser (Global Genomics), and managed by Anna Dickinson, Senior Policy Analyst, Public Policy Projects.

The contents of the report is based on over 9 hours of discussion amongst over 70 participants drawn from academia, industry, national genomics institutes and wider civil society. The project cohort reflects the truly global reach of genomics, including participants from over 10 countries and five continents. We are grateful to each of them for sharing their time, knowledge, and expertise, which has informed and built the body of this report.

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In June 2020 Public Policy Projects (PPP) launched the World Economics Series (WES) in collaboration with the London Diplomatic Community and The Diplomat Magazine. The purpose of this work, out of which this Global Genomics Programme was conceived, is to focus on drawing out the importance of collaboration between countries.

Genomics played a pivotal role in enabling the sequencing of the virus, serving to greatly deepen our understanding of it. It was this central role that led to the rapid development of functional vaccines. This marked an unprecedented global achievement. Science, and more specifically genomics, had come to the rescue. The speed of vaccine development, during an unprecedented global health crisis, marks the standard which can be achieved through global scientific and genomic collaboration. One which must be upheld in the future. This principle marked the overarching theme that this report sought to untangle and address.

The genomics revolution, which the world has witnessed over the past three decades, has served as a welcome reminder of the capacity to conceive new solutions to health challenges previously considered insurmountable. However, this revolution would not have been possible without close collaboration between national governments, other funding agencies and genomics specialists all around the world.

The importance of genomics in dealing with current and future global public health threats has been highlighted, reinforcing the importance of international collaboration and the benefits that can be derived from such a coordinated response. However, if this is not appropriately supported and developed, the desire to continue such collaborative work shall be cut off before it is able to emerge from its infancy. Genomics has proven its value however, the present lack of global oversight or a shared approach towards the needed regulations and guidelines to ensure an equitable global market and industry, presents the need for this present chasm to be addressed or the sentiment of collaboration will fade away and dissolve into national genomic silos.

This programme of work focused on how to bring the benefits of genome sequencing to the world, bringing together a unique cohort of experts from across the genomics ecosystem and from the diplomatic community worldwide. At its core, it examined the fundamental importance of continuing to have global collaboration in the field but also explored the challenges which face enabling such collaboration. Including the need to create a more diverse and interconnected dataset that would facilitate such collaboration so that the benefits of genomics could truly be enjoyed equitably around the world.

Foreword

FOREWORD BY RT HON STEPHEN DORRELL

In June 2020 Public Policy Projects (PPP) launched the World Economics Series (WES) in collaboration with the London Diplomatic Community and The Diplomat Magazine. The purpose of this work, out of which this Global Genomics Programme was conceived, is to focus on drawing out the importance of collaboration between countries.

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Rt Hon Stephen Dorrell
Executive Chair, Public Policy Projects
1. A Global Charter for Genomics needs to be established and enforced which addresses:
   a. issues of equity of access and return in global genomics; and
   b. sets the overarching policy framework for sharing the benefits of participation in genomics which needs to involve all aspects of the genomics ecosystem; and
   c. establishes a framework of permitted use of sequenced human genomes so that data is not misused and continues to be available for research and clinical purposes.

Without such a Charter there will be a reluctance to provide access to or share data which will impede the progress of genomics globally and restrict the ability to bring the benefit of genome sequencing to all. The recommendations of GA4GH with respect to standards of genomic data should be adopted by all.\(^1\)

2. Genomics has played a vital role with respect to the COVID-19 pandemic and significant capacity has been created and deployed globally by Governments and research institutions. Political and financial support for this capacity needs to be maintained even when the initial threat recedes and priority should be given to individual jurisdictions being enabled to develop their own genomic interpretation, analytical and diagnostic capabilities so that benefits can accrue in countries globally.

3. There are legal and regulatory considerations around the sharing of genomic data. Advances in technology – such as public cloud – also mean that it is possible to provide federated access to genomic data, in a way that maintains data protection and privacy requirements. This is particularly beneficial given the scale of genomic datasets, as cloud infrastructure is well-suited to store, process and analyse them. Countries could explore these different options, including ‘data stewardship’ models, to facilitate more collaboration in the use of genomic data.

4. Public trust and engagement with respect to participation in genomics is complex but must be sensitively and deliberately considered right from the outset. When consent is sought, transparency is essential and it is imperative that organisations do not go beyond that which they have obtained consent to do.

5. There is a scientific, ethical, social and political imperative to ensuring that there is true global representation in genomics, both in terms of the datasets from which scientific and clinical innovation is derived but also in the wider genomics ecosystem as a whole if the benefits of genome sequencing are to be made available, equitably, to all.

6. There are limited studies of the economic benefits to be derived from participating in genomics and there is no consistent approach globally about how this is assessed. Greater policy focus needs to be applied to how this should be considered, for example through the lens of the wider societal benefits that can be derived, so that all jurisdictions are able to make a better assessment of the economic potential for them of focusing on genomics if genomics is not to become the preserve of only jurisdictions or organisations that can afford to fund it.
The genus of this programme of work was to explore how to bring the benefits of genome sequencing to the world. The Human Genome Project (HGP), first articulated in 1998 by a special committee of the US National Academy of Sciences and later adopted through a series of five-year plans jointly prepared by the National Institutes of Health and the Department of Energy, had the ultimate goal of the complete mapping and understanding of all the genes of human beings, all of those genes together being the genome.

From the outset the entire HGP was centred around two key principles – firstly, by welcoming collaborators from any nation in an effort to move beyond borders and to benefit from diverse approaches and secondly, by requiring that all human genome sequence information be freely and publicly available within 24 hours of its assembly. This ensured unrestricted access for scientists in academia and in industry, thus enabling rapid and novel discoveries of researchers of all types.

International collaboration and open access data have therefore been cornerstones of genomics since its inception. And yet, notwithstanding the vision, articulated by President Bill Clinton in 2003 when the first draft sequence was announced, that “we must ensure that new genome science and its benefits will be directed toward making life better for all citizens of the world, never just a privileged few”, access to the benefits of genomics is not equally available to all. And in part that is driven by the fact that the datasets which exist do not reflect the diversity of the global population.

This was at the heart of this programme of work – to explore how this lack of diversity has the potential to exacerbate health inequalities that we know exist and what steps need to be taken to address this. There is a myriad of inter-connected issues that contribute to these challenges and the purpose of this programme of work was to convene a unique cohort of stakeholders and subject matter experts from a variety of jurisdictions to identify and explore the policy issues that need to be addressed.

Without question, the role of genomics in response to the COVID-19 pandemic has shone a spotlight on the powerful contribution this field can make, both in terms of development of the vaccines and monitoring of the virus but also with respect to informing the development of policy and public health responses. This Programme of work considered the lessons we can learn from this unique global response, but particular focus was given to sequenced human genomes. The wider application of genomics beyond the field of human healthcare did not form part of our discussions.

Our intention was not to duplicate work carried out by other organisations but to socialise that work to a wider audience. We intentionally created a platform for different voices and perspectives to be heard uniquely bringing together academics, clinicians, ethicists, lawyers, international agencies, industry partners and members of the diplomatic community, from jurisdictions with developed genomics programmes and ecosystems and those at the very start of their journey and, importantly, from high and low-and-middle-income countries. We did not lead with the science but with policy. An issue that was raised time and again was the urgent need to address equity, both of access and return, with respect to genomics. If this is not addressed there is a serious risk that nationalistic and protectionist tendencies will intervene which will impede the progress of genomics globally.
The rate at which genomic information is being generated is growing rapidly, with Stanford recently earning a Guinness World Record for sequencing an individual’s DNA makeup in just over five hours. Considering the first sequencing took 13 years, the field is growing at an extraordinary rate, and we must ensure the world, as a whole, is able to benefit; not simply a few select nations.

This report collates the insights that were shared on the key themes that were discussed. It was a pleasure to Chair these discussions and to work so closely and collaboratively with such a cohort of experts.

Kate Orviss
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REALISING THE INTERNATIONAL POTENTIAL OF GENOMICS AND THE NEED FOR AN INTERCONNECTED APPROACH

Throughout history, science and research have benefitted from collaboration, and the COVID-19 pandemic has created new collaborations which will benefit humanity for years to come. However, whether that example continues to ignite the desire for further global collaboration or dissolves into national and organisational silos remains undetermined. Both the scientific and political worlds are faced with a great opportunity; further developing international collaboration networks is essential if the benefits of genomics are to be delivered around the world.

Science, and more specifically genomics, have been at the heart of the fight against COVID-19. This fight has witnessed the global scientific community come together to develop drugs, vaccines, monitor the evolution of the virus, study the spread of it, and develop policies that have informed governments on how to contain the infection.

International collaboration is essential, and the recent pandemic saw organisations recognise the need to openly and freely share their publications to aid further development in controlling the virus. They reflected a sector-wide acknowledgement of the need for open and honest outputs. This sense of collaboration must be preserved.
As a subdivision of science, genomics is founded on global collaboration, as evidenced initially by the Human Genome Project, which demonstrated how governance could be achieved jointly by scientists and policymakers from multiple countries. This fundamental principle of global collaboration, involving the scientific community and the wider genomics ecosystem supplemented by effective public policy, is the premise on which this paper is based. We believe it is vital that such global collaboration is maintained and developed. The COVID-19 pandemic and the application of genome sequencing of the SARS-CoV-2 virus globally, has demonstrated the ability of science to respond to a global public health threat and as a result brought genomics to the forefront of public consciousness, raising awareness of the field’s power and utility. We need to capitalise on this wider appreciation of genomics.

Science diplomacy provides the catalyst to promote scientific discourse that unifies researchers across borders despite political tensions among nations. The SARS-CoV-2 pandemic is the first contemporary global crisis that has affected virtually every person on the planet at the same time and is a stress test for the relationship between science and politics. International research collaboration in this field led to an unprecedented breakthrough in relation to the development of vaccines at record speed and COVAX is a unique global collaboration with more than two-thirds of the world engaged.

But, despite these successes for collaboration, vaccine campaigns continue to provide more of a battle for international leadership and geopolitical influence than the global cooperation and solidarity that is demanded.

**CASE STUDY 1 EMBASSY OF FRANCE IN LONDON: UK-FRANCE GENOMICS COLLABORATION**

Scientific diplomacy has a long history as a catalyst to promote scientific discourse that unifies researchers across borders. Science can also have a leverage effect to tackle global challenges. In the field of cooperation in genomics, as part of the UK-French summit held in Sandhurst in 2018, the UK and French governments announced enhanced cooperation between Genomics England and the French Médecine Génomique 2025 project. This strategic genomic medicine partnership marks a strengthening of the existing relationship between Genomics England and the French National Institute of Health and Medical Research (Inserm). It is a perfect example of when a research collaboration programme contributes to cementing the political bonds between countries.

Even though global collaboration may from the outset appear to be the solution, the system is far from ideal. The discussions which helped form this report drew out key themes, which will repeatedly emerge within the body of this report. If they remain unaddressed, they will stunt the development of a global genomics ecosystem that is equitable for those who participate.

1. **Dataset Diversity**

The global genomics dataset is not representative of the global population and more needs to be done to address this. This is important from the perspective of equity with the attendant
II. Public Trust and Engagement

Public trust and engagement are crucial, but they need to be carefully and sensitively managed by clear articulation of the benefits of genomics and recognition that there can be significant, and in many cases understandable, mistrust. The exploitation of the Henrietta Lacks genome, which was used for commercial benefits without any benefit or even knowledge of her or her family, is a good example of this, but one that does not exist in isolation.9

Science has the ability to tackle global challenges and operate without borders but is not always neutral and can serve different if not opposed interests. Presenting facts is sometimes not enough to convince the public. The public perception of the risks of genomics is very different from the scientific perception; both perceptions need to be addressed if the objectives of the policy are to be delivered.

III. Regulation and Standardisation of the Dataset

There is inevitably a balance to be struck between national decision making about the use of data and the desire of the research community to have access to comparable data drawn from globally diverse sources. The work of the Global Alliance for Genomics and Health (GA4GH) is important in this regard,10 because it focuses on the need to address proper public concerns about and the dangers of genomic information falling into the wrong hands.11

There is a need for a set of rules to be developed which apply to all companies to ensure patient data is not misused, is available for research and clinical purposes in the right settings and in a framework that respects the right of each country to make its own decisions about how to apply data privacy standards. This will create a level playing field for all companies operating in the field and should help to build public trust and confidence that things will be done for the benefit of the public, for the benefit of patients and national health systems, not individual corporate entities.

IV. Enhancing Healthcare

There are serious inequalities globally, in relation to access to genomics and healthcare generally, and it is important to recognise that these inequalities will undermine the development of genomic research programmes if they are not addressed.12 Exploring and articulating how the significantly enhanced global capacity for genome sequencing, which has arisen during the pandemic, can and should be deployed is timely and important.

Our work has reinforced our view of the importance of genomics in dealing with current and future global public health threats, but it has also served to reinforce the importance of international
collaboration and the benefits that can be derived from such a coordinated response. It is important to recognise that the practice of collaborative working, although it is widely supported, is not yet entrenched and institutionalised. It is therefore an important objective of policy to provide a framework that encourages collaborative behaviour, and it is a fundamental requirement of such a framework that it provides for equitable governance.

**CASE STUDY 2**

**ELIXIR: BEYOND 1 MILLION GENOME (B1MG) PROJECT**

The B1MG project is an EU-funded Coordination and Support Action coordinated by ELIXIR. The project aims to create the legal guidance, best practices, and recommendations to create infrastructure to enable the commitment of the 1+MG signatory countries to give cross-border access to at least one million sequenced genomes. Multiple countries, partners, and institutions across Europe, and beyond, work towards defining and implementing a 1+MG Trust Framework and sustainable access to personalised medicine data across Europe. The initiative provides guidance to associated countries to implement the Trust Framework at a national level in national healthcare and research systems.

Early stakeholder engagement has been critical to establishing the technical specifications and implementation guidelines for federated secure cross-border access to genomic data and personalised medicine data. The requirements for data quality, standards, technical infrastructure and Ethical, Legal and Social Implications (ELSI) are being developed into guidelines set under the 1+MG Trust Framework. Whilst these guidelines are being established by and for the signatory countries, they are available for any stakeholder via the B1MG stakeholder portal or are openly accessible via well-known repositories. These guidelines may be applicable to other countries on a global scale. Standards are being used from global standard-setting organisations, such as GA4GH, that will pave the way for collaboration beyond Europe.

At a country level, several activities aim to support national genomic plans, capacity, and aid sustainability. For example, activities to develop groups that mirror the activities of the 1+MG initiative at a national level are underway. Further to this, a B1MG Maturity Level Model (MLM) has been developed and defined to create an optimisation path to aid the adoption of genomics in healthcare systems at a national level. The MLM is a common matrix for countries to self-evaluate the level of maturity of national/regional genomic medicine practices. A panel of experts across Europe have validated the matrix and reached a consensus. The next phase will be to pilot the use in healthcare systems from various countries or regions. In addition, three virtual capacity building country visits were held to countries with advanced genomic medicine programmes (the United Kingdom, Estonia, and Finland) to learn about the implementation of genomics in healthcare systems and promote knowledge exchange between European countries. During these visits, signatory countries described their current national status in the 1+MG initiative and genomic medicine and health plans.

Further to this, there are activities that are working towards how to articulate the economic benefits of genomics. To be able to aggregate data on a European level, best practices are shared and a common approach for economic evaluation is stimulated, and a framework will be developed. This includes discussions on the wider economic benefits of whole-genome...
sequencing for individuals and society. Responsible industrial involvement in 1+MG national programmes is foreseen to drive innovation in genomics-based health and personalised medicine. In addition, a Genome of Europe multi-country project has recently been launched to generate 500,000 whole-genome sequences for a federated European reference genome data collection. These sequences will be generated within the 1+MG trust framework and will increase the diversity of genomic data that is accessible at the level of individual countries and across Europe, for research and healthcare.

Figure 2 & 3 - Submitted by Wellcome Sanger Institute
The development of the pandemic has demonstrated that even though genomics and genome sequencing played a vital role in understanding and tackling past viral outbreaks and controlling their development and spread, the global community was insufficiently prepared for what was to come next: the COVID-19 pandemic.

Producing genomic information that aids in the establishment of exposure histories and the tracking of infection rates, has now become a pre-requisite step in the effective control of emerging or potential spreads. Genomic data has empowered researchers to estimate the rate of potential genetic evolutions and mutations.

Databases that render samples and genomic data readily available provide a vital resource and crucial information in enabling the origin and sequence patterns of viruses to be quickly identified. Reinforcing the observations made while examining the value of genomic sequencing in combatting the spread and developing an understanding of Ebola, SARS, and MERS highlights the value of sharing genomic information on a global stage. This is reflected through the use and value offered by databases such as GenBank, which can be accessed irrespective of where the scientists or research team are based.

**Case Study 3**

**Wellcome Sanger Institute: Sequencing SARS-CoV-2**

We strongly champion open release of data, including resources, protocols, materials and publications we produce. Through open engagement and collaboration with the scientific community worldwide, the Sanger Institute empowers genome research across the globe.

An exemplar of this is that Sanger Institute staff have contributed approximately 20 per cent of the world’s publicly available SARS-CoV-2 genome sequences. The data are used for identifying and tracking viral variants, tracing COVID transmission in the UK, and aiding public health responses to the pandemic. Available to researchers worldwide, the sequence data are also aiding understanding of the virus, its evolution and its biology.

A detailed analysis of SARS-CoV-2 genomic surveillance data shows COVID-19 in England as a series of overlapping epidemics. The study has helped researchers understand more about how a new infectious agent spreads and evolves.

In March 2020 the COVID-19 Genomics UK (COG-UK) consortium was established. The aim was to monitor the spread and evolution of SARS-CoV-2 by sequencing the virus’s genome. The Sanger Institute was the sequencing hub of COG-UK and is now reading more than 60,000 coronavirus genomes per week for the UK Health Security Agency (UKHSA) – contributing around one-fifth of the world’s publicly available SARS-CoV-2 genome sequences.

Analysis from the work of the COG-UK Consortium and the Sanger Institute revealed a series of sub-epidemics that peaked in early autumn 2020 and the emergence of the Alpha variant. In March 2021 they detected the first samples of Delta which appeared in sequence data in England.
Our experience with COVID-19 has demonstrated that viral infections affect not only the health of a population but also the country’s economy and infrastructure as well. Genomic sequencing empowers researchers and those on the ground to investigate and respond, ‘to disease outbreaks before they become a global threat’. Advances in genomic sequencing and mapping have provided a wealth of knowledge to clinicians, epidemiologists, and public health responders during outbreaks of high-consequence viral disease. Sequencing the genome of a virus, identifying its entire genetic code, and sharing such information currently only takes a matter of days. It also enables the science, public health, and healthcare sectors to come together to tackle outbreaks. Genomic sequencing and databases built by international collaboration enable researchers to reconstruct evolutionary relationships between different genetic sequences. Although genomic sequencing and data have played and will continue to play, a vital role in the generation of understanding about the genetic make-up of a virus, it does not mark the end of progress in the field.

The Sanger Institute continues to deliver large-scale genomic surveillance of SARS-CoV-2 in near real-time, and the data are passed to the UK’s public health authorities to inform the pandemic response.

To view the lineages and variants detected in the UK, see https://covid19.sanger.ac.uk/lineages/raw
The COVID-19 pandemic has demonstrated that it is possible and necessary both within countries and between countries, to break down silos and for public health systems, academia, industry, politicians and policymakers to work together in support of the application of genomic science to a better understanding of the virus.\textsuperscript{23} This connected and coordinated approach is essential and must continue to be supported scientifically, politically and financially, even when the immediate danger of this pandemic has passed so that the infrastructure remains in place to deal with the next pandemic.

We believe there needs to be a greater political and institutional focus on preparing for the next global health crisis. We know it is coming, we just don't know when. This is what the discussions held in this programme of work highlighted.

This imperative has the following essential elements:

1. There needs to be a greater political focus on the importance of sharing genomic data globally. This is not purely a moral and ethical issue, but a scientific imperative if the benefits of genome sequencing are to be maximised, whether in response to this or future pandemics or to human health more generally. Fundamental to this focus needs to be addressing the equitable return of benefits to those who contribute as without equitable benefit sharing data silos and data protectionism will follow which will curtail the progress of genomics.

2. Policymakers across different countries need to understand why the sharing of genomic data is beneficial and ought to be promoted whilst at the same time considering the conditions under which data should be shared so that this does not undermine the interests of their populations.

3. Data sharing as a term can be confusing as often genomic data, particularly with respect to the human genome, is not shared but rather accessed as it is held in a controlled and federated system to which access is granted and the data never leaves the jurisdiction in question.\textsuperscript{24} This is an important distinction.

4. Investment in technology and the workforce is crucial and need to be used in conjunction with an operational response to driving an effective response to a pandemic.

5. Genomic sequencing capacity has been deployed globally in response to the pandemic,\textsuperscript{25} but the continued investment is required to ensure the sustainable availability of this capacity for the future. There are benefits to accrue from the utilisation of genome sequencing capacity beyond responding to a pandemic and these need to be championed.

6. Greater investment is needed in relation to the provision of analysis and interpretation tools with respect to genomic data, particularly in low-and-middle-income countries, as this will enable benefits to accrue in the country. Technology can democratise access to the tools needed for this analysis and interpretation, such as public cloud technology which does not require large or upfront investment.

7. Other economic levers need to be deployed, potentially from agencies such as the World Bank, to create small and mid-size enterprises (SMEs) in those countries that have access to data to develop low-cost diagnostics in their own country which could assist with building a genomics ecosystem in that country rather than seeing the benefits accrue elsewhere.
To make this an equitable ecosystem governments and organisations need to look beyond their own national and immediate interests. Success will depend on how much each player can feasibly contribute. Examples exist of both national institutions and private organisations taking steps in the right direction to ensure that we are as prepared as possible for the next pandemic (see Case Studies 3 & 4), but a more coordinated effort is needed.

**CASE STUDY 4**
**GENOME CANADA: SEQUENCING THE CRISIS: HOW GENOMICS MORPHED FROM A COVID-19 RESEARCH TOOL TO A CRITICAL PART OF THE PANDEMIC RESPONSE**

The creation of the Canadian COVID-19 Genomics Network (CanCOGeN) was announced on April 23, 2020, under Canada’s federal government’s coronavirus research and medical countermeasures investment. The network, managed and coordinated by Genome Canada, stems from leadership by federal departments such as Innovation, Science and Economic Development Canada (ISED), the Public Health Agency of Canada (PHAC) and Health Canada, where Deputy Ministers convened various leaders’ roundtables on COVID-19 to create policy synergies and coordinate the different components of the federal COVID-19 response.

There was a lot of work to be done after the initiative was launched by Genome Canada and the six regional genome centres, with a commitment to sequence within 24 months up to
150,000 viral samples and up to 10,000 genomes of patients diagnosed with, or exposed to, COVID-19. This included “hard infrastructure” (the machines and other equipment needed to do the sequencing), and “soft infrastructure”, setting up sharing protocols, standardising data analysis, and ensuring data was shared and governed by appropriate privacy and security measures. Other important deliverables of the network were additional training and personnel and increased capacity in bioinformatics, computational biology and epidemiology. Canada’s decentralised healthcare system was already presenting challenges, nonetheless a necessary network effect across provinces starting to happen to build a national consortium.

PHAC had been created following the SARS outbreak that hit Canada in the early 2000s to build out a national public-health response, but it lacked the sustained funding and investment to enable preparation for ‘the next pandemic’. There certainly wasn’t the scale of investment necessary to build and maintain a national genomics surveillance system. CanCOGeN was forging a largely new structure to respond to SARS-CoV-2.

Before the COVID-19 pandemic, there was a lot of work underway to get PHAC’s National Microbiology Laboratory (NML) and the Canadian Public Health Laboratory Network (CPHLN) ready for the onboarding of genomic technology, as the next real sea change in the way that diagnostics and particularly surveillance was being done in Canada. Like any major transformation, it was not an overnight achievement.

COVID-19 accelerated these plans, and indeed things needed to happen overnight, to put it mildly. CanCOGeN was initially conceived as a surveillance and research initiative, with implications for vaccines and outbreak investigations. Most importantly, CanCOGeN’s objective since the outset has been to inform public health and policy decisions across Canada. But the biological significance of virus variants that would come along, like the Alpha and soon the Delta strain, meant that the genomes needed to be looked at with a higher degree of fidelity and much faster turnaround time than what was initially envisioned.

Meanwhile, provincial labs were creating new internal structures and scaling up existing capabilities to deal with the crisis. Contributing to this big national effort was not necessarily top of the provinces’ priority lists, which left CanCOGeN to establish common ground, build political will and encourage buy-in. Additionally, the labs needed funding and other resources just to create the bandwidth to feed up into that national system.

**CASE STUDY 5**

**ILLUMINA – AIDING GLOBAL DEVELOPMENT OF GENOMIC CAPABILITIES**

In October 2020, as part of an ongoing commitment to enable genomic capabilities in low- and middle-income regions, Illumina donated USD $1.4 million worth of sequencing systems and related consumables to the African member states, through the African Union, and Africa Centres for Disease Control and Prevention (Africa CDC).
Illumina also joined a cross-sector public-private partnership to support the Africa CDC Institute of Pathogen Genomics in launching the Africa Pathogen Genomics Initiative (Africa PGI). The comprehensive initiative will expand access to Next-Generation Sequencing (NGS) tools and expertise with the goal of strengthening sustainable pathogen genomics capacity across the continent, including capacity building in 20-plus countries. Illumina will donate NGS platforms, reagents, and training support worth approximately USD $20 million over four years. Other partners in the US $100 million initiative include the US Centres for Disease Control and Prevention, the Bill & Melinda Gates Foundation, Oxford Nanopore Technologies, Microsoft, and others.

Additionally, this year Illumina, in partnership again with the Bill & Melinda Gates Foundation, committed an incremental USD $40 million in sequencing capabilities to broaden the Africa PGI model to additional geographies, starting with South Asia. This will help create a comprehensive pathogen genomics network around the world, building critical public health capabilities in areas of need. This will serve not only the immediate pandemic response but also will lay the foundation for better management of emerging and endemic diseases and bring us closer to the vision of an early warning system for global pathogens.
Genomic data initiatives are expanding rapidly around the globe. Their efficacy and potential were demonstrated during the COVID-19 pandemic as nations began to establish a long-term investment in pandemic surveillance and responses.\(^2\) It is imperative that the global genomic community, and other relevant parties, explore how relevant data is collected, stored, processed, and integrated with other datasets.

Owing to the rapid expansion of the field of genomics, understanding the implications of international and national data protection legislation and regulations can be complex. However, existing precedent within established frameworks can inform the development of best practice for supporting the provision of secure access to genomic data.

The European Commission has, for example, launched an inquiry into the potential creation of a patient-centric and trustworthy ‘European health data space’\(^2\). This investigation reflects high levels of commitment to make the best use of EU citizens’ data for the benefit of EU citizens’ health while operating within the legislative framework created by the GDPR.

In recognition of the importance of working together to create a unified approach to secure sharing of genomic data, GA4GH has developed the ‘Framework for Responsible Sharing of Genomic and Health-Related Data’.\(^2\) The primary challenge however lies in convincing international actors, government, policymakers and organisations to subscribe to such a framework of governance. It is thus essential that the international genomic community continues discussions into the most effective mechanisms for collaboration with respect to genomic and related data.

**CASE STUDY 6
PHG FOUNDATION: THE GDPR AND GENOMIC DATA – UNDERSTANDING THE IMPLICATIONS FOR RESEARCH AND HEALTHCARE**

The PHG Foundation’s legal experts were funded by the UK Information Commissioner’s Office to examine the impact of the European Union’s General Data Protection Regulation (GDPR) on the processing of genetic and genomic data in healthcare and health research.

The GDPR is a complex regulation that impacts the processing of citizens’ personal data, with a significant global impact. It also forms part of current UK law, alongside the UK Data Protection Act 2018. The UK genomics community – who collaborate extensively with counterparts around the world - have an urgent need to understand exactly how the concept of ‘personal data’ applies to genomics, and what the regulation means for both research and healthcare.

The 2020 report from the PHG Foundation, ‘The GDPR and genomic data’ report, provides a detailed legal analysis of the many ways in which the GDPR impacts genomic healthcare and research, highlights areas for urgent attention, and makes recommendations for the genomics community, regulators, and policymakers to maintain the flow of genomic data for effective healthcare and scientific research.\(^2\)

This research assesses the current and likely near-future impact of the GDPR and UK Data Protection Act 2018 on the uses of genetic/genomic data in healthcare and health research.
In particular, it addresses three linked research questions with significant practical importance for regulators, health services, clinical professionals, scientists, patients, and the public:

- To what extent do genetic/genomic data used for healthcare and medical research in England and Wales count as ‘personal data’ under the GDPR?
- To the extent that they are ‘personal data’, what is the impact likely to be on the delivery of health and social care in the short-to-medium term (up to five years)?
- What can be done to mitigate or reduce any negative impacts?

Working with clinical and scientific professionals, policymakers, regulators, and academic experts, the PHG Foundation found that the central challenge for the genomics community is uncertainty about how the general Regulation applies to the highly specific context of genomic data. This ranges from the fundamental, determining when genetic data are or are not ‘personal data’, to the more specific, such as identifying appropriate legal bases for transfer of genomic data outside the EU/EEA or determining how data subject rights apply to ‘shared’ genetic data.

The report identifies a number of promising technical and organisational measures that may be adopted to ensure compliance with the Regulation and achieve the clarity needed. These include technical measures which may be taken to safeguard genomic data while facilitating analysis, such as homomorphic encryption, and organisational, sector-led initiatives such as the development of formal codes of conduct (art 40) or certification mechanisms (art 42).

The measures will enable the genomics community and data protection experts to work together to reach a legally recognised consensus about the application of the GDPR in genomic healthcare and research.

Cloud technology will play a central role in enabling the management and storage of large-scale data sets. Through its ability to provide on-demand technology without the need to invest heavily in physical hardware, cloud technology greatly enables the democratisation of access to data as well as the storage, compute power and analytical tools required to analyse it.

While cloud technology providers typically ensure the security of the cloud infrastructure, the data controller remains responsible for securing the data that is in the cloud, including determining access permissions and setting appropriate security controls in accordance with the relevant regulatory framework. Cloud technology providers offer a range of tools and guidance to support customers with security.

Additionally, the volume of insight that is likely to be available over the next decade is such that no single organisation will be able to independently manage, sequence, process and analyse all insight available from a particular data set. It will require smaller, agile groups looking at specific problems to really accelerate this field, allowing exponential development of insight drawn from the data. Cloud technology is well suited to support this, as it democratises access to the storage and compute-intensive tools required to make use of genomic data. Cloud technology’s inherent scalability and flexibility also lend themselves well to genomic data processing, storage, and analysis: the computing power required can be adjusted in near-real-time to meet the requirements of an organisation or individual.
The concept of ‘data sharing’ warrants further discussion: in many cases, existing legislation allows for data to be shared, subject to appropriate security and privacy controls. There are also alternatives to sharing data, such as the provision of data access, as explored above. Policymakers should consider the appropriate terminology to use when discussing how data is stored and access is provided.

Attention must also be given to the need for interoperability and standardisation between data sets as the extent to which the data can effectively be used will be dependent upon where it can be used to make inter-set comparisons.\(^{31}\)

It is also important to recognise that although the ability of institutions and organisations to source, fund and generate their own datasets will vary, they have an important shared interest in facilitating effective data collection and usage.

**CASE STUDY 7**
**AMAZON WEB SERVICES: GENOMICS ENGLAND DEVELOPS GENOMICS AND HEALTH INFORMATION PLATFORM ON AWS TO TURN SCIENCE INTO HEALTHCARE**

To make genomic healthcare a reality, Genomics England (GEL) is transitioning from project to platform, using Amazon Web Services (AWS) tools to give researchers reliable, comprehensive, and privacy-compliant access to these massive datasets. Through secure collaboration and analysis, this initiative will inform diagnoses, drive drug development, and unlock the future of precision medicine.

**Enabling Scalability for Growing Genomic Datasets**

Through the 100,000 Genomes Project alone, GEL amassed 50 petabytes of data – about three times the size of the entire Library of Congress. Seeking to make the data accessible to the research community, GEL is in the process of migrating its data to AWS to enable democratised access. To generate a more comprehensive understanding of patient genomics, the organisation will integrate “long-read” genome formats alongside the current “short read” format. Long-read genomes contain around five times the data of short read, and this will give researchers more information about each part of the genome they study, potentially uncovering nuances that might have gone unnoticed before.

**Turning Science into Healthcare through Technology**

GEL’s mission is to create a scalable and durable data infrastructure that can evolve in tune with scientific and technological advances. Security, compliance, and democratised access were integral to the research platform, and GEL selected AWS Partner Lifebit to develop the platform on the AWS. Together with AWS, they have created a Trusted Research Environment (TRE) that will allow researchers to work collaboratively and glean insights from genomic data using advanced cloud computing tools. GEL is working with AWS Professional Services and AWS Partner Kainos as part of the AWS Migration Acceleration Program (MAP). By migrating petabytes of genomic data and on-premises research environments to AWS, GEL can help accelerate scientific outcomes. Using analytics and tooling in the cloud also makes the data more secure. Genomic data stored in Amazon Simple Storage Service (Amazon S3) offers 99.999999999 per cent durability.
For genomic analyses and related computing needs, GEL is using Amazon Elastic Compute Cloud (Amazon EC2), unlocking reliable, resizable compute capacity in the cloud. This allows researchers and data scientists to adjust their compute capacity on-demand, which is more cost-effective. Sinden also pointed out that operating on a pay-as-you-go basis is ideal for academic and government-funded research because it allows for flexibility to accommodate fluctuations in grant funding. Building on AWS with the help of its partners, GEL optimised its high-performance computing architecture for both cost and speed, allowing researchers to perform common tasks in just 23 seconds that previously took 25 hours.

Building the Future of Cloud Genomics on AWS

While many big data problems involve managing many small files, genomics analysis usually involves a relatively small number of extremely large files. As a result, cloud genomics requires unique data distribution models. GEL is working with AWS to use compression technologies and other advanced tools to optimise cloud storage and analysis of genomic data based on the field’s specific needs. This industry-leading venture will pave the way for efficient, research-friendly genomic data management in the years to come.
Genomic data is not intrinsically valuable; its value arises when it is combined with other forms of biomedical data, for example, health records. For maximum benefit, the data must be as close to real time health data as possible. It, therefore, must be considered how the benefits derived from this data should be shared with the patient, organisation, health system and beyond.

There are therefore two questions:

• How can as much benefit as possible be derived from genomic data?

• How should the value associated with the benefit be shared?

Interest amongst the public in submitting their genomic data for greater clarification on their ancestry and potential health hazards is growing fast. Over 26 million consumers had opted to add their data and DNA samples to the databases of the four leading commercial ancestry and health organisation by early 2019,\textsuperscript{32} and that number has since grown.

Although these databases are potentially valuable, the terms on which they have been collected mean they are not normally available for scientific research. As the price of sequencing continues to fall it is important to understand the potential uses of such data, what data needs to be gathered, the consent models which govern how it is used, and how it is used in clinical versus research environments.

Building upon themes already explored in this report, it is important that these databases comply with standards of interoperability and standardisation. If society is to benefit from the clinical as well as research benefits that are available, it is important that the policy framework is put in place to allow this to happen.

The core principle of that framework must be the informed consent of the citizen. It is therefore essential to be upfront regarding how provided data will be used and what for.\textsuperscript{33}

It is within the power of the citizen to consent to their data being used, but their views may change, and it is therefore essential that the consent model allows for the changing views of individuals over their life course.

In considering consent models it will be beneficial to draw from existing examples of best practice and success. For example, there are examples of how people interact with their credit scores or credit reports where there have been several drives to make this more accessible to people. In that case, the citizen can see who has accessed their data, when they accessed it and what they accessed it for. Citizens can also opt-in and out of being a blood donor in the UK, which can be monitored through an app.\textsuperscript{34}

Personal health data, including clinical data, exists in an environment with substantial legislative and regulatory governance. This framework needs to reflect the principle of dynamic consent to cover both the changing views of the individual and the changing uses of the data. In this model, consent is better seen as continuing engagement rather than a transaction (“tick in a box”) at a moment in time.
It is important that the consent model applied by the regulators is sufficiently flexible to reflect the issues which arise in personal health data. These are primarily around the sensitivity of the data and the importance of public and patient support, but also need to take account of the practical issues caused by the volume of the data which were covered in the previous chapter. Suitable regulation and guidance for scientific, life sciences and genomics research is thus essential.

Specific concerns are also raised about sharing of data with specific partners – for example, pharmaceutical companies and national governments. Concerns are consistently raised with respect to whether data can be identified, placing the trust and engagement needed from the patient in jeopardy.

This is a complex field and there are multiple different consent models in use which include different forms of broad consent, specific consent, and dynamic consent. Detailed consideration of these questions lies outside the scope of this paper, but it is an important priority for regulators to ensure that the regulatory framework is consistent with the wider policy objectives described here.
DIVERSITY IN GENOMIC DATA

It is widely understood and recognised that genomic and related data is being produced and archived at a prodigious rate, and that current studies, as this report has outlined, hold the potential to become historical baselines for developing global genetic diversity analyses and monitoring programs.

The data collected during and in connection with the COVID-19 pandemic provides such a baseline. While this database provides a valuable starting point, however, the shortage of genomic data, beyond Europe and North America, is a substantial impediment to the delivery of a healthcare revolution to the global population. Improved participation by populations outside Europe and North America will substantially increase the quality of genomic research and the inferences drawn from it for people of all backgrounds.

If the world is to collectively prepare for the next pandemic, it must be assured that the data collected to monitor, track, and evaluate how viruses, such as COVID-19, reflects the world around us. If we fail to make that change, the derived benefits will continue to be skewed in favour of those the data reflects, reinforcing already existing and entrenched global health inequalities.

The need to generate greater diversity and representation across genomic data sets is gradually becoming more widely recognised. It must be acknowledged therefore that there are many underlying factors that impede the achievement of greater diversity within genomic data. Factors that stretch beyond the confines of simply diversifying the data sets.

Focusing firstly upon the need for greater diversity within the dataset, it must be recognised that many of the groups which are underrepresented suffer from health inequalities with roots that lie deep in their history. Too often their data has been misused or used unethically, their communities have not received just reward for contributing their data. The levels of engagement and trust amongst such communities are, unsurprisingly, low, and it is important to engage with them and earn their trust.

Several themes emerged from our work with regards to bettering community engagement. It is clear that high levels of fear and concern remain surrounding genomics but what is key is remembering that countries and communities need to be empowered and engaged to find their own solutions and use their data for their own public health and policy decisions.

Secondly, cost plays a large role in limiting participation within genomics and genomic sciences. Across the world, there is a select number of states which can boast of the necessary infrastructure and training capacity to develop and maintain a prosperous genomics ecosystem. For example, in countries in which fewer samples and sequences are being conducted, the cost is greater per each sequenced genome which means there is a greater challenge and cost to scale up the sequencing capabilities.

Programmes across Canada, Australia, the UK, the continent of Africa and more, exist to tackle such limitations to participation. Their aim is to propose greater collaboration within their own minority and Indigenous communities to promote greater awareness and engagement across the field of genomics. It is also important to build the necessary physical and human capacity in jurisdictions looking to establish their own genomics hubs and institutions; these developments need to find solutions that work within their own national contexts without a ‘Western saviour’ approach being enforced upon them or adopted.
Change, however, will not simply be achieved by creating a more diverse database; there is also a global need to create a more diverse research culture. This will require a different approach to the peer review process, allocation of funding grants, selection of cohorts and editorial boards as well as building capacity locally. 39

Against this background, there needs to be a global dialogue about the nature of ‘equity’ in the context of genomics. At its core, any definition of equity must include the opportunity for a universal benefit and the realistic prospect of the opportunity being realised.

If there is to be a global dialogue to focus on what we mean by equity this would need to look long term and think about how the benefit of data sharing is returned to the contributing communities and researchers. We need to address the fact that through the COVID-19 pandemic there has been a widespread commitment to data sharing across the globe: one which we must continue to match going forwards, to ensure the full extents of benefits to be derived from such data remain accessible to as many people and research institutes as possible.

Sharing is a two-way process; too often the experience of low- and middle-income societies has been that they have contributed access to data but have not received access to the benefits derived from it.

This leads directly to money. Is it realistic to expect governments to attribute funding to a genomics programme now when the benefits are seen as speculative at best? This is broader than pandemic preparedness – it is more about the purpose of genome sequencing capacity.

Funding will need to come from a variety of sources including profit making organisations. But we need to create the environment for that conversation to happen and for all organisations to feel that they are being treated fairly.

It should also be remembered that technology can contribute to making it more straightforward for genomic data to be collected, stored, processed, and analysed, as is reflected in Case Study 2. 40 The main challenges will be human challenges; trust and inclusion and respect, incentive, purpose and all those things that create a sense of humanity. The pandemic has been a powerful mobiliser, but it has also brought to light many of the existing disconnects.

Finally, it must serve as a stark reminder that if issues, such as diversity, are to be addressed within genomics; it is not appropriate or sufficient to simply look at each issue in isolation. The addressed issues must be examined and considered holistically because they are all intertwined.

The objectives are clear:

- Science offers us the opportunity to deliver effective healthcare and personalised medicine by considering the most accurate genetic information to ‘assess disease risk, prevention and treatment for a given individual’, irrespective of the individual’s or patient’s ethnic background. 41

- Public policy must ensure this opportunity is taken.
CASE STUDY 8
H3AFRICA: ENSURING NO CONTINENT IS LEFT BEHIND

While health-care professionals in developed countries are increasingly being given access to such facilities and expertise, the relevant skills, infrastructure and governmental support for these activities are currently lacking on the African continent, and reference data and scientific knowledge on African-specific disease variants are scarce. Additionally, the data used to inform precision medicine are largely skewed toward European populations, where the number of potential candidate variants associated with diseases tends to be lower than in other populations, such as those of African descent. Discoveries from H3Africa research will be used to develop and improve disease diagnostics, explore the use of genetic risk-prediction algorithms for complex traits in African populations, and augment drug discovery and development.

Precision medicine is being enabled in high-income countries by the growing availability of health data, increasing knowledge of the genetic determinants of disease and variation in response to treatment (pharmacogenomics), and the decreasing costs of data generation, which promote the routine application of genomic technologies in the health sector. However, there is uncertainty about the feasibility of applying precision medicine approaches in low- and middle-income countries, due to the lack of population-specific knowledge, skills, and resources. The Human Heredity and Health in Africa (H3Africa) initiative was established to drive new research into the genetic and environmental basis for human diseases of relevance to Africans as well as to build capacity for genomic research on the continent. Precision medicine requires this capacity, in addition to reference data on local populations, and skills to analyse and interpret genomic data from the bedside. The H3Africa consortium is collectively processing samples and data for over 70,000 participants across the continent, accompanied in most cases by rich clinical information on a variety of non-communicable and infectious diseases, both rare and common. These projects are increasingly providing novel insights into the genetic basis of diseases in Indigenous populations, insights that have the potential to drive the development of new diagnostics and treatments.
As the world continues to grapple with the impact of the COVID-19 pandemic, this paper has highlighted the benefits to human health which are available from a global genomic ecosystem. But realising these benefits requires the investment of financial and human resources in the life sciences industry which represents a major challenge for many countries and may simply appear unaffordable when seen in the context of competing priorities.

When these priorities are being assessed; however, it is important that genomics is seen as an economic opportunity as well as a public health imperative.

If the public policy framework is properly structured, these economic opportunities are open to low- and middle-income countries as well as richer countries.

For some, genomics may present the opportunity to address rare diseases; for others, the greatest impact on population health may be felt through pharmacogenomics. It is in the interests of all countries to develop partnerships that identify the opportunities available in each country.

Within the UK the initial objective for the £300 million GBP of taxpayers’ money spent on genomics was to secure the adoption of genetic medicine within the NHS. To address this a national test directory was developed to test the impact of adoption on outcomes; it showed that children born with a genetic disorder after 2003 spent a median of six years waiting for diagnosis and attended at least 68 hospital appointments. This resulted in around £15,000 GBP per person being spent without securing a diagnosis and between 2003-2017 amounted to over £87 million GBP being spent over a small number of cases.

In addition to government funded programmes; genetic medicine is attracting growing numbers of public private partnerships around the world. This trend is reflected in the UK Biobank and Our Future Health programmes; both are public private partnerships in which the government put up some money, and in which commercial partners are involved.

It should be an important objective of policy to secure public private partnerships which make the data democratically accessible, and which provide legitimate rewards for those for put capital at risk to support scientific and clinical development.

If it is effectively integrated into national health systems, genomic science has the potential to revolutionise both healthcare provided to the individual, and the health outcomes experienced by the wider population.

Beyond the traditional economic benefit markers of job creation, intellectual property, and commercialisation, it is also crucial that policymakers unpick and understand the broader impacts provided by genomics. In assessing genomics as a driver for national economic growth, whether they are publicly or privately funded, nations must look beyond the confines of healthcare.
Perceptions about genomics are changing, as more organisations and nations recognise the economic and health benefits which are available. For example, in Canada, the 2021 national budget categorised genomics as a prioritised field of investment for the wider Canadian economy which was not categorised simply as health expenditure. Genomics is seen as part of the innovative economy of the future which the budget strives to promote. The Canadian Government is supporting a Pan-Canadian Genomics Strategy, in which genomics is seen both as an innovative sector and key platform technology (like artificial intelligence (AI) and Quantum computing) which needs to be developed to drive economic growth.

The Canadian policy framework places significant emphasis on talent development through training programmes and education systems. The purpose is to ensure that the implications of policy objectives are thought through, and - in the example of genomics – judged by the full range of potential outcomes including, for example, the potential impact of genomics to help drive lower

CASE STUDY 9
GENOMICS THAILAND: AN INNOVATION-DRIVEN ECONOMY, STARTING WITH A COMPETITIVE GENOMIC MEDICINE INDUSTRY

Pharmacogenomics research began in 2004 in Thailand. Several variants have been identified in the Thai population, including HLA-B*15:02 for carbamazepine. Pharmacogenetic testing has also been implemented nationwide. At Ramathibodi Hospital alone, around 3,000 patients have benefited from pharmacogenomics and personalised medicine and received partial reimbursement for some drugs.

In early 2019, the Thai government approved a $150 million five-year initiative to catalogue the genomes of 50,000 citizens. This project, named the Genomics Thailand Initiative, aims to expand the understanding of South-East Asia’s under-represented genomic composition and advance Thailand’s genomics capabilities in personalised diagnostics, drug selection and treatment in various disease areas. Thailand pursued precision medicine research as early as 2004 through the Thai Pharmacogenomics Project for Stevens-Johnson syndrome (SJS) and toxic epidermal necrolysis (TEN) screening, with investments from the Thai Ministry of Science and Technology.

The project used genetic testing to identify epilepsy patients at risk of developing these severe responses to a widely prescribed generic medication, and ultimately reduced such cases by 80 per cent in 2018. Continuing its precision medicine efforts, the most recent Genomics Thailand Initiative falls under the broader remit of the Thailand 4.0 government campaign to close the middle-income country gap towards an innovation-driven economy, starting with a competitive genomic medicine industry.

This demonstrates the effective use of public funding for precision medicine approaches as an upper-middle-income country, first within Stevens-Johnson syndrome and toxic epidermal necrolysis (TEN) in 2004, now into larger-scale five-year genome catalogue initiatives (2019).
carbon emissions (important for a green economy) or driving more agricultural productivity, greater crop resilience in climate resistance agriculture and improved food security, particularly in remote areas where food costs are prohibitive.

The argument for investing in genomics is clear, but many governments around the world may feel it is beyond their capacity. It is therefore imperative that the introduction of genomic services is dependent upon the capacity and needs of the nation or healthcare ecosystem.

Building upon Case Study 9, in Thailand, the health economic evaluation of genetic testing as a preventative tool for Stevens-Johnson Syndrome (SJS)/TENS demonstrated that it reduced cases from 1300 per annum (2019) to 300 (2021).53 The 2019 figures marked the highest number of recorded cases of SJS per population in South-East Asia. Thus, a fall in numbers by over 300 per cent in just a few years, following the introduction of a genetic test to address the high numbers of SJS, reflects the positive impact the investment in genomics and genomics medicine has made. In implementing and funding a genomics programme Thailand has brought down the numbers of adverse reaction cases by 80 per cent since 2009.54

Although the use of genetic testing techniques is not common across South-East Asia – introducing interventions has proven to be demonstrably cost-effective for the health system. Thailand is demonstrating such benefits, through incremental development, and analysis of total societal cost and gain, rather than maintaining a narrow focus on the health system.

If pharmacogenomics for example can ensure people stay ill for less time, and can alleviate pressure, and cost from national health services and return to participating in society and contributing to the economy sooner; then the return on investment in genomics and genomic capabilities can be very attractive.

This is an opportunity for the global community to come together to support the development of genomic capabilities which are appropriate to their context. An international framework that supports the development of genetic science would bring substantial benefits to both human health outcomes and economic development in all participating countries.

**CASE STUDY 10**
**THE HONG KONG PERSPECTIVE: ECONOMIC BENEFITS DERIVED FROM PARTICIPATION IN GENOMICS**

The Clinical Genetics Team in the Department of Paediatrics and Adolescent Medicine, the University of Hong Kong, has taken active roles in scientific research to evaluate the clinical and economic benefits of participation in genomics.

Next-generation sequencing technologies, including rapid whole-exome sequencing (wrest) offers the potential for early diagnosis-predicated precision medicine. A study was conducted by the Clinical Genetics Team to examine the diagnostic and clinical utility and the economic benefits of rWES on acute care in 102 families in Hong Kong. This paper was published in the Lancet Regional Health Western Pacific in 2021,55 and was highlighted by PHG Foundation on their website.56 In this cohort, Hong Kong was able to achieve an international comparable diagnostic yield of 31 per cent, and the diagnosis made was able to impact clinical management
in 88 per cent of diagnosed patients. Cost analysis revealed that by providing rWES, it was estimated to reduce hospital length of stay by 566 days and decrease healthcare costs by HKD$8,044,250 (GBP £796,460). The avoided healthcare costs far exceeded the costs of providing rWES for the entire cohort, with the net economic savings being estimated at HKD$5,325,187 (GBP £527,246).

The economic benefits were reflected through investment in genomic technologies. While rWES is an expensive diagnostic test, costs associated with unnecessary hospitalisation, management procedures, professional fees, and treatment medications produced large cost-savings. Further economic benefits would be expected in longer-term cases with lifelong medications and hospital readmissions. Other intangible benefits could potentially lead to further cost-savings, including family cascade testing, reproductive planning, management implications in ‘variant of unknown significance’ (VUS) cases, and possible early detection of problems from long-term surveillance.

Our case in the Hong Kong setting has illustrated the economic benefits reflected through investment in equipment and manpower. With economic benefits being recognised in the clinical setting, it is anticipated that economic benefits will also be derived from a broader societal perspective, such as cost-savings from improved productivity or the ability to work, and less of a caring burden.
Conclusion

The world finds itself at a juncture at which it can either recognise the need and value in global collaboration generating a global genomic ecosystem or turn back and return to working in silos that prioritise national interests over global public health and economic development. Since the completion of the sequencing of the first human genome in the year 2000, it has been recognised that "we must not shrink from exploring that far frontier of science. But as we consider how to use new discoveries, we must also not retreat from our oldest and most cherished human values. We must ensure that new genome science and its benefits will be directed toward making life better for all citizens of the world, never just a privileged few."57

This report has built upon the transformative work displayed during the COVID-19 pandemic, which witnessed the world come together to track the monitoring of the SARS-CoV-2 virus however the end is not in sight. More remains to be done.

The genomics revolution, which the world has witnessed over the past three decades, has served as a welcome reminder of the capacity to conceive new solutions to health challenges previously considered insurmountable. However, this revolution would not have been possible without further and continued close collaboration between national governments, other funding agencies and genomics specialists all around the world.

It is now a shared understanding that the SARS-CoV-2 virus will continue to mutate, rendering global surveillance efforts essential, as highlighted by South African efforts to detect, track, and flag the emergent Omicron variant.58 Global surveillance is essential if it is shared understanding that future pandemics are a certainty. If as declared in the Universal Declaration of Human Rights, ‘everyone has the right... to share in scientific advancement and its benefits’, the global community must do more to protect the many and not the few.

Genomics can aid in the achievement of this, but that is only the start. If we learn the lessons of the pandemic and put in place a global framework to encourage and share its development, making use of the latest technology, genomics is a science that can transform many aspects of our lives.

Figure 8 - Biobanque Génome Québec et CIUSSS du Saguenay-Lac-Saint-Jean, Provided by Genome Canada
Sources

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18. For example and reference see Case Study 4 on page 15 of this report.


20. See for example and reference see Case Study 4 on page 16 of this report.


25. For more information on standardisation please review the work of GA4GH: https://www.ga4gh.org/.


See page 10 of this report.


See for reference: UK BioBank, Available at: https://www.ukbiobank.ac.uk/ (accessed November 2021); Our Future Health, Available at: https://ourfuturehealth.org.uk/ (accessed November 2021).


