Chapter

Harnessing Small Country Collaboration Opportunities to Advance Energy Innovation and Joint Investments

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Abstract

Greater international collaboration is required to catalyze research and development (R&D) investment flows in energy technologies. Successful deployment of such technologies requires innovative funding mechanisms, intellectual property, and data-driven analyses to make smarter, sustainable investment decisions. As small countries are increasingly dealing with effects of climate change, some are projected to lose large portions of their economy. This chapter discusses ways that smaller countries, both in the developed and developing world, can harness international cooperation to advance energy innovation and mitigate such impact. In contrast to collaboration with larger countries, smaller country collaboration can build more agile, balanced partnerships in which participating countries co-develop and co-own R&D and training, and define pilot programs that target their own needs. Leveraging each other's strengths, small countries can become catalysts for global change. Smaller country collaboration is explored through a proposed model of collaboration in energy innovation between Singapore and Estonia, often considered gateways to Southeast Asia and the EU plus Russia, respectively. Specifically, Singapore and Estonia have the opportunity to leverage each other's startup ecosystems, innovation systems, knowledge-based economies, and regional markets to build a niche in clean energy technologies, particularly energy storage innovation, with potential global impact on larger markets.

Keywords: energy innovation, technological advancement, small country collaboration, bilateral partnership, Singapore, Estonia

1. Introduction

Greater international coordination and collaboration is required to research, develop and deploy reliable and affordable energy technologies critical to achieving global emission reduction targets. In turn, successful deployment of such technologies may require innovative funding, intellectual property, and data sharing strategies [1]. As small countries are increasingly dealing with effects of climate change, some are projected to lose large portions of their economy to climate change, which will require creative solutions to help mitigate this impact [2, 3]. Innovative clean energy technologies can enable countries to achieve their carbon emission reduction

goals and empower them to set more ambitious goals for the future [4]. For small countries, one opportunity cost of not implementing innovative clean energy technologies is the impact on projected carbon emission reduction goals.

Fewer self-funded opportunities for independent innovation and research within smaller countries provide an incentive for these countries to seek opportunities for international joint innovation and collaboration [5]. While small countries often collaborate with larger countries that have more research and development (R&D) funding, technical assistance, and expertise to bring new technologies to market, such cross-border collaboration can lead to imbalances in ownership, accountability, and decision making.

This chapter introduces the concept of small country-to-county joint innovation, discusses the benefits and criteria for collaboration and concludes with a proposed example of joint partnership in energy storage innovation between Singapore and Estonia. Smaller country collaboration can build more agile, balanced partnerships in which participating countries co-develop and co-own R&D and training, and define pilot programs that target their own needs. Leveraging each other's strengths, small countries can become catalysts for global change.

2. Why small countries matter

According to French writer Milan Kundera, "What distinguishes the small nations from the large is not the quantitative criterion of the number of their inhabitants; it is something deeper. For the small nations, existence is not a self-evident certainty but always a question, a wager, a risk; they are on the defensive against history, that force which is bigger than they, which does not take them into account, which does not even notice them [6]."

Kundera's assertion is backed up by the creators of the Global Innovation Index, which measures a country's innovation impact based on innovation inputs (such as higher education) and outputs (such as knowledge creation) [7]. As the world has increasingly globalized, small countries such as Singapore, Switzerland, and the Baltic countries have become "innovative by necessity [8]." Larger countries, on the other hand, innovate out of ambition and competition. This common attitude towards innovation and survival among small countries creates shared goals through which strong international partnerships can grow. Even large countries and regions such as the United States, China and the European Union stand to benefit from such partnerships and cooperation if their firms can design better products for fast-growing small country economies.

Joint innovation partnerships between small countries also require a form of matchmaking that differs from collaboration with larger countries. First, the countries must understand the comparative advantages and national innovation systems of the other to determine whether, between the two countries, they have the expertise and resources to co-innovate on any given project. Second, small country collaboration will presumably require each to risk a larger proportion of their own resources than if they were collaborating with a larger country. However, each country may enjoy greater benefits from success. This section describes the benefits of small country joint innovation and the criteria for creating a balanced partnership.

2.1 Why small countries should pursue joint energy innovation

Climate change is increasingly affecting all countries with varying degrees of impact, and current climate models point to carbon dioxide emissions as

a primary factor causing climate change. Individually, small countries, both developed and developing, are helping to lead the charge. For example, while Switzerland's overall emissions are small relative to larger countries, its emissions per capita are above average. Thus, the country believes it has a responsibility to reduce its carbon emissions, and influence other countries, such as Brazil, to do the same [9]. In Eswatini, a low carbon emitting country, the country showed leadership and innovation in reducing hydrochlorofluorocarbons (HCFCs). HCFCs are a type of greenhouse gas used in refrigeration and air conditioning. The country worked in partnership with the United Nations, a German environmental organization, and Eswatini's local refrigerator manufacturing facility to phase out the use of HCFCs [10].

While the examples above do not represent small country joint collaboration, they do demonstrate the will of small countries to take part in the call to action against climate change, which has the potential to lead to future small country collaboration. Collaborative joint energy innovation and investments between small countries has the potential to have impact on:

- National policy: carbon dioxide reductions from clean energy technology implementation can potentially impact a greater proportion of a small country's energy resources and advance its energy goals.

- External support: small countries that are nimble, early adopters of new technologies can attract commercially-focused suppliers eager to assist successful demonstrations of innovative products.

- Investment focus: small countries can maximize the value of their joint investments when serving as test beds for innovative technologies focused on their own needs.

- Economic growth: the combination of smaller countries' capabilities and resources in joint projects can lead to economic growth in sectors where each has existing strengths, with mutual benefit from successful technology propagation.

- Future success: successful collaboration in one area, such as energy innovation, can lead to other opportunities for smaller countries, their industries and their people to further collaborate in other areas with mutual benefit.

These reasons are especially attractive for small countries, such as small island developing states (SIDS) that are most vulnerable to the effects of climate change. For SIDS, such as Tuvulu, that are at risk of disappearing from sea level rise due to climate change, joint collaboration in energy innovation could be critical to its survival. Successes in joint innovation between small countries that are dealing with similar challenges can be applied to other small countries as well as larger countries or regions dealing with the same challenges [11].

2.2 Challenges that small countries face

Small countries face several challenges that joint collaboration with larger countries or multilateral organizations often address. Many are finding innovative ways to address the majority of these issues, which could be used in small country joint collaborations to fill the gap left by the traditional role of larger countries. These challenges include:

1. Scale: smaller domestic markets typically limit economies of scale, which makes scaling up and deploying a new innovation more expensive. Larger countries remedy this issue by bringing access to large markets and deployment opportunities. However, some small innovative countries are often gateways to regional markets, which, with the right partnership and connections, can be a catalyst for scaling innovation. In the clean energy sector, according to the World Resources Institute, no one country dominates, signaling that there is still opportunity for small countries to play a role in regional or global supply chains [12].

2. Lack of global influence: larger countries tend to have more influence in international institutions and decision-making, making it harder for smaller countries to be heard on a global stage. In addition, small and developing countries run the risk of playing a "marginal and subordinate role" in international collaboration networks, making it difficult for them to influence the research agenda [13]. Increasingly, institutions such as the United Nations have started holding panels on small country success stories [14]. This type of international platform for small countries could incentivize more small countries to develop successful, innovative models for joint collaboration.

3. Lack of administrative capacity: according to a study on small states, innovation, and administrative capacity, small countries are particularly challenged by the administrative needs of growing international networks and influence that are a by-product of innovation [15]. One way that Israel deals with this challenge is that it drives much of its research in collaboration with research laboratories in other countries to free up its own R&D funding and capacity for other parts of its innovation system [16].

4. Lack of technological expertise or human capital: larger, developed countries have a larger talent pool for R&D. While small countries typically cannot compete on sheer quantity of talent, several small countries have programs that leverage both domestic and foreign talent. For example, Singapore has a funding program for nationals that incentivize them to return to the country after pursuing graduate studies in foreign countries [17]. Estonia takes a different approach, and encourages its entrepreneurs to start or join startups abroad, which could ultimately bring business and economic growth back to the country [17].

5. Lack of financial capacity to fund R&D: for smaller countries, limited domestic financial resources and harder-to-access international financing can stifle energy innovation. Several innovative financing options are discussed in Section 3.1.

6. Rapid changes in innovation: depending on their structure, small country economies could be severely impacted by 'creative destruction' caused by the cycle of innovation and technological change in which new jobs, industries, and products replace old ones [15]. Larger countries can afford to be more resilient to these types of changes, which makes 'creative destruction' less risky financially and with regard to skills and products. Small countries can mitigate the effects of 'creative destruction' by establishing strong yet flexible institutional capacity that can adapt to changes in innovation and the resulting demand for new skills and products [17]. In addition, a stronger focus on downstream innovation, which focuses on commercialization of early-stage

innovation, will help mitigate the risk of an innovation succumbing to the 'valley of death'. This focus could slow down the pace of 'destruction' by helping to prolong and diversify resources across the innovation cycle.

7. Overspecialization: limited domestic markets, fewer resources, and dependence on exports creates a risk for small countries to overspecialize in a certain product or skill, making the country less resilient to changes in innovation and less diverse economically [15]. Although small countries often use specialization to drive economic growth, they can ensure that policy incentives and funding mechanisms incentivize innovation to move up the value chain to avoid lock in.

2.3 Benefits of small country cross-border innovation collaboration

Small country collaboration can provide several benefits to participating countries that they would not be able to have with larger country partnerships.

First, while the proportion of resources, and thus risk is higher with small country-to-country innovation, small countries can co-innovate and deploy technologies with bigger impact to a network. In larger countries, pilots are often proven on a small-scale in communities or parts of communities. In some cases, for example, pilot programs do not see the same impacts and same benefits at scale, partially because of regulatory, economic, or constraints that were not imposed on the pilot [18]. In smaller countries, while pilots might be at a smaller or similar scale overall compared to a larger country, a deployment can demonstrate impact on a full national or sub-national ecosystem, including government, economy, and community networks, rather than a more siloed pilot program.

Second, small country collaboration can be more nimble and efficient. Similar to the difference between a large corporation and a small business, smaller countries have less 'red tape' to navigate, and can make decisions and deploy resources more quickly, leading to more a more flexible and effective partnership. More nimble partnerships could in turn facilitate more frequent information sharing and greater formal and informal networks for knowledge transfer. This, in turn, can lead to greater communication and an opportunity for the countries to help each other improve their innovation systems. However, for example, in imbalanced partnerships between developed and developing countries, knowledge transfer often does not happen due to a more passive role by the developing country [19].

Third, smaller countries can co-develop and co-produce research, training, and pilots that will truly benefit their needs, and allow them to be empowered through decision making, leadership, ownership, and financial accountability. These countries can build more targeted partnerships that will truly leverage the other's strengths and build impact and value for each other through development of technical skills and technology transfer capability. One research study observed that collaborations with small scientific communities tend to be restricted to specific fields of research that are directly linked in some way to participating countries [19]. For example, small countries use specialization in R&D intensive sectors, such as energy and technology, to drive economic growth [15]. However, these types of opportunities allow small countries to find direct or complementary linkages that are relevant to a larger audience. These linkages create opportunity for small countries to join forces, engage together with larger countries or markets, and bring scale to their innovation. For example, as we discuss in Section 4, Estonia's innovation in cybersecurity and Singapore's electric grid testbed creates opportunities for joint innovation for grid security.

Fourth, small country joint collaboration can open up opportunities to learn lessons and share successes from each other, specifically that address challenges unique to small countries. For example, small countries may not have to worry about how its R&D decisions will influence global trade flows, but they may want to share ideas about how to influence decision making in international organizations that are dominated by large countries.

Fifth, and finally, according to a joint United Nations Intergovernmental Panel on Climate Change (IPCC) and ClimateXChange panel on climate change action in small countries, small country joint collaboration can spur global advocacy and activism leadership on environmental issues [14]. For example, Scotland has leveraged international cooperation to inspire other small countries to reduce their greenhouse gas emissions through innovative initiatives [14]. SIDS countries have also joined together to draw attention to the need for innovation in addressing climate impacts. Together, small countries can make their voices heard on an international stage.

2.4 Criteria for creating a balanced partnership

Traditional cross-border innovation collaboration often focuses on bilateral and multilateral partnerships among international organizations' member countries, where collaboration arises between developed and developing countries, and regional cooperation. While small country-to-country collaborations already have a place in the sphere of cross-border joint innovation, opportunities exist outside the traditional paradigms of collaboration. Smaller countries may collaborate to apply their respective capabilities to new technology developments of high relevance and importance to them. For example, a study on Norway's innovation system found that international collaboration between foreign and Norwegian researchers on scientific research increased from 23% to 53% between 1985 and 2004 [20].

However, this trend reflects that international collaboration in general, as measured by co-authorship and publications, has been growing over time, with co-authored articles doubling over the past two decades [19]. While reasons for this trend range from increasing globalization to the rise of the internet, small countries typically rank highly in international collaboration based on this measure. Research shows an inverse relationship between the size of a country and international collaboration [5].

While this measure of co-authorship and publication is a verifiable and measurable method of determining international collaboration, it does not measure the level of contribution by each participating country, nor the level of joint innovation that truly occurs. A study on the effect of unbalanced international collaboration on a country's real contribution to scientific output found that countries with smaller scientific communities produced an 'insignificant' level of scientific output in unbalanced partnerships [19].

International collaboration, especially in the form of joint innovation, is an especially valuable opportunity to actively contribute to solving world challenges, such as food security, water issues, and energy security. Just as it's important to have inclusive participation and decision making in all levels of government, for example, small countries too should have a seat at the table. Smaller country collaborations are more likely to produce balanced partnerships.

Some research suggests that the topic of collaboration has some bearing on the type of partnership. A study of 20 countries of varied size found that collaboration on 3D printing technology yields more balanced collaboration, big data technology shows a more radial pattern with the United States in the center, and carbon nanotubes and graphene technology indicates "small-world," clustered networks [21].

While none of these technologies are specifically energy technology, researchers should be aware in advance of how their target area of research might yield preferences towards a certain type of partnership.

In addition, the research supported their hypotheses that the bigger the country, as measured by their level of knowledge reserves and the level of R&D full time equivalent (FTE) innovators, the less incentivized the country are to engage in international joint collaboration [21].

What criteria are important to building a successful small country-to-country collaboration partnership? Not every small country partnership combination is ideal–just like any partnership, it depends on the goals and commitment of each country. Joint innovation and collaboration requires a level of resourcing and commitment that not every country may have.

Often, geographical location, known as the 'neighborhood effect', can spark direct, indirect, and spillover effects between small countries neighboring each other [22]. While not a requirement, geographic proximity can come with built in mutual benefits (cross-cultural understanding, similar time zones, etc.).

Regardless, small countries with certain characteristics may have higher chances of successful cross-border partnerships.

These characteristics include [17, 21]:

- Openness to outside ideas and opportunities
- Strong and flexible institutions
- Regulatory and policy environment that supports the end-to-end innovation cycle
- Strong talent pool with engaged research network

The Institute for Management Development (IMD) publishes a world competitiveness yearbook every year, which ranks countries based on their investment and development, appeal and readiness [23]. This ranking includes investment in education, quality of life, and opportunities for career advancement. In IMD's 2019 ranking, several small countries were in the top 10, including Singapore, Qatar, and Switzerland [23]. Other rankings, such as the World Intellectual Property Organization's Global Innovation Index, World Economic Forum's Enabling Trade Index, and other indicators of innovation and entrepreneurship can help identify small countries that have criteria for a successful cross-border partnership.

3. Key strategies for successful joint innovation

Successful small country joint innovation will require purposeful shifts from traditional approaches to development, including embracing open innovation, enabling a strong investment environment, fostering an entrepreneurial ecosystem domestically, and engaging with collaborators under win-win intellectual property strategies. These shifts will enable the flexibility and equal voice that small countries need in joint collaboration, and may also benefit these countries economically well beyond the scope of energy technology innovation. This section discusses key enabling strategies for successful small country joint collaboration, which includes innovative funding mechanisms, intellectual property tools, and creative data sharing.

3.1 Funding mechanisms

Developed countries have a history of funding partnerships between developed and developing countries, which often start with the developed country first developing a study and then engaging with developing country partners for pilots or testing grounds. Traditionally, funding comes from government agencies, research councils, or other sources with R&D-focused goals. But these programs can end when the funding ends, absent committed resources in developing countries; or can result in loss of control to large countries that retain critical skill sets and establish outside economic or political influence.

Small country-to-small country energy innovation requires funding and resource commitments that become a priority for the countries and lead to sustainable initiatives. Innovative funding approaches to funding can include:

- Leveraging regional funding initiatives, such as Horizon 2020 or Mission Innovation, which coordinates global RD&D for clean energy [4].

- Jointly funding an innovation challenge that would create a pull incentive for innovators to propose new ideas.

- Directly funding collaborative domestic capabilities that support the research goals, thereby shifting the accountability to agencies and individuals on both sides that are motivated to successfully develop a more collaborative and balanced partnership [24].

- Developing Public-Private Partnerships (PPPs) that provide attractive investment of private funding to build sustainable infrastructure.

- Engaging in international joint energy technology innovation partnerships that attract venture capital funding. For example, SkeletonTech, an Estonian supercapacitor startup, originally received funding from an Estonian-Norwegian joint energy technology innovation program in 2013 and has received at least one round of venture capital funding [25].

- Focusing on downstream innovation, such as the deployment and scale-up of successful innovations through business development organizations. Business development organizations can create business plans that clarify the supply chain, value chain, path to market, and regulatory hurdles and help assure timely access to target markets for energy innovation to avoid commercialization "valley of death."

- Establishing entrepreneurial incubators and special grants for piloting promising innovative technologies or necessary building blocks to avoid the technology development "valley of death."

Each of these mechanisms can help enable small country joint innovation and provide opportunities for small countries to find funding that will make joint innovation possible without larger countries or multilateral institutions.

3.2 Intellectual property

Innovative approaches in intellectual property (IP) that foster investment in new technologies will facilitate intra-country commitments, technology transfer,

and private in-country investment needed to introduce and establish a sustainable technology innovation.

Patenting and licensing should be at a pace consistent with commercial opportunities, and should set forth a clear plan for rapid technology transfer that benefits both countries. The commercial upside for both countries will require standards for protection against loss of technical information and limit any unwanted diffusion of energy technologies through industries and continents [1].

One licensing example is the cluster approach, in which IP that is developed through publicly-funded projects is made available through commercial licensing to other organizations [1]. In addition, PPPs should establish up-front expectations of efficient and rapid technology diffusion so that private sector concerns with risk mitigation and IP protection are proactively addressed to protect private investment and do not hinder the diffusion process.

IP rights ownership should be planned up front for a win-win model, and while this includes IP ownership by partners who generate new innovations, the plan needs to assure the costs of IP protection, IP rights and economic returns are shared to facilitate collaboration.

Where IP rights are jointly owned by several countries or partners whose contributions are interdependent, as would be expected in a small country-to-small country collaboration and related PPPs, each country and participant would be expected to grant non-exclusive, royalty-free rights necessary to enable small countries to implement innovations in-country, and to provide a commercially reasonable sharing of economic returns from government and private investment in new technology deployed outside their respective countries.

The goal of such win-win collaboration in innovation is to enable each partner to obtain rights to use the project results that maximize commercial exploitation and share in commercially reasonable returns subject to additional agreements. One example from large country collaboration is the US–China Clean Energy Research Center, which aims "to accelerate the pace of innovation in clean energy technologies [1]." The organization has had success through clear guidelines for licensing, joint ownership, and dispute resolution.

3.3 Data sharing

Data sharing, enabled through open and flexible data flows between countries, can be a critical component in all stages of innovation. For example, in marine energy projects funded by the U.S. Department of Energy, international researchers help determine how data will be shared on a global level [26]. Since small countries do not benefit from the volume of data and number of users that larger countries have, data sharing or data-focused trade agreements can help incentivize small country joint innovation opportunities [26]. In addition, data sharing and joint collaboration can help with developing metrics to evaluate the value and potential of energy technologies in the R&D phase. Finally, as innovation in energy technology reaches the commercialization stages, data sharing can help inform standards development for new technologies [1].

4. Case study: Singapore-Estonia joint energy storage innovation collaboration

The model of smaller country collaboration is explored through proposed energy innovation collaboration between Singapore and Estonia. Singapore and Estonia are often considered gateways to markets in Southeast Asia and the EU plus Russia, respectively. Specifically, Singapore and Estonia have the opportunity

to collaborate and leverage each other's startup ecosystems, innovation systems, knowledge-based economies, and regional markets to build a niche in energy storage innovation with potential global impact on larger markets [27].

4.1 The Singapore-Estonia connection

This section outlines Singapore and Estonia's current international cooperation, which reveals regulatory and business environments that can welcome collaboration on energy storage technologies. Currently, there is no explicit energy technology innovation cooperation between Singapore and Estonia [28]. In the past, Estonia has looked at the regulatory sandbox approach adopted by the Energy Market Authority (EMA) in Singapore, but found that the current regulatory framework in Estonia is flexible enough for starting businesses and there is no explicit need for a regulatory 'safe space' such as the one in Singapore [28]. Singapore's regulatory sandbox model was developed in 2018 to support energy innovation in generation, transmission and distribution, and creates a trial environment in which third parties can test energy solutions without being subject to regulatory requirements [29]. This sandbox allows promising innovations that may not comply with current regulatory requirements to be tested and deployed and allows the EMA to assess potential impacts of new technologies when deciding whether to modify or add new regulations.

However, in other areas, such as entrepreneurship, the two countries have found growing opportunities for collaboration. Enterprise Estonia, which negotiates and manages investment from outside of Estonia to its country with counseling programs for startups, opened its Singapore office in September 2016 [30]. The office promotes trade relations with Singapore and connects the booming startup community in Estonia with Asian venture capital, and uses Singapore as a launch pad to the South-East Asian (SEA) region for Estonian startups. Estonia in return offers opportunities for e-Residency to SEA business people for easy access to the EU and for managing their EU businesses [31].

In 2016, Estonia simplified its e-residency program, which allows Singaporean e-resident applicants to pick up their cards directly in Singapore instead of at an Estonian embassy in another country as Estonia does not have an embassy in Singapore. The e-residency allows entrepreneurs to establish and operate a company in Estonia remotely, and is the most efficient way of getting benefits like easy access to the EU market, e-banking services, and a streamlined digital administrative system. Thus, a Singaporean entrepreneur can establish an Estonian company that he runs from Singapore, to serve clients based across the European Union [30]. According to Estonia's chief information officer (CIO) Taavi Kotka, Singapore is one of Estonia's highest priorities in terms of collaborating with developers and service providers in one of the top global startup ecosystems in the world [32].

In addition, in January 2018, Estonia and Singapore signed an agreement on cooperation between the countries by which the countries create the possibility for joint exercises at the cyber practice fields in both countries [33]. In May, the Estonian Defense Forces Cyber Range provided a cybersecurity training at Singapore's Cyber Defense Test and Evaluation Centre (CyTEC) [33]. While no explicit energy technology innovation collaboration is currently planned between the two countries, the two countries have developed a relationship that would welcome energy technology innovation collaboration.

4.2 The case for energy storage innovation collaboration

This section makes the case for joint collaboration specifically focused on innovation in energy storage between Estonia and Singapore. The three sub-sections

focus on domestic energy storage markets, regional energy storage markets, and how Estonia and Singapore could benefit from joint innovation in this sector.

4.2.1 Domestic markets for energy storage

Although Estonia's government lacks a near-term goal explicitly focused on energy storage, several startups and universities in the country are bringing energy storage technologies through the innovation pipeline, from R&D to commercialization. The country uses its ecosystem of universities, venture capital, startup culture, and science and technology park, Tehnopol, to spur innovation and primarily develop products for export [34]. Estonia's climate roadmap, however, suggests that energy storage innovation may be key for the country's future. Estonia is currently the most energy independent country in the EU due to its abundance in oil shale, but has the highest energy intensity of all OECD countries [35].

In order to reduce its reliance on oil shale, which is responsible for 90% of electricity generation and 80% of Estonia's greenhouse gas emissions, the country is looking to diversify via investment in renewables and will heavily rely on wind power by 2040 [36]. By 2025, a significant portion of shale power generation units in Estonia are scheduled to be shut down due to environmental restrictions related to air quality [37].

Estonia is integrated into the Nord Pool spot trading market. Unless government strategies change, in 2025 Estonia would become dependent on international cooperation to supply a stable source to complement its intermittent wind resources, thus reducing its energy security. In addition, according to the World Energy Council, since wind resources in Estonia and its neighbors are highly correlated, geographic integration will not fully mitigate potential intermittency problems, making the case for new energy storage capacity [36]. This future projection could be a catalyst to spur energy storage R&D for domestic purposes in Estonia.

In Singapore, on the other hand, the government has a stated focus on energy storage, with Singapore's Energy Market Authority having started an Energy Storage Program in 2015 to improve the stability of Singapore's power system and included the launch of its Energy Storage System (ESS) testbed in October 2017 [38]. Singapore currently relies on natural gas for 95% of its electricity needs, but has a national target to deploy 350 MWp of solar PV by 2020, which is the most promising renewable source available in the country [39]. There are no hydro resources, wind speeds and mean tidal range are low, and geothermal energy is not economically viable [40].

At the end of Q1 2018, Singapore had 115 MW of installed solar capacity making up approximately 0.8% of Singapore's total energy mix [40]. This is a tangible step towards the national target for 2020, reflecting Singapore's commitment to solar PV.

According to the Economic Research Institute for ASEAN and East Asia, Singapore's solar PV mix will increase to 8% of Singapore's energy mix by 2030 [39]. A study by the Sustainable Energy Association of Singapore presents a more aggressive mix, stating that solar energy could possibly meet as much as a quarter of Singapore's energy needs in 2025 [41]. However, due to the intermittent nature of solar, there are limitations to deploying solar on a large scale to generate electricity reliably in Singapore. The ESS testbed is thus seen as an important factor in enabling solar adoption in Singapore [42]. Singapore aims to develop a niche in energy storage and batteries to first ensure domestic energy security and to further explore applicability to regional and global markets. International cooperation agreements have also been a key part for Singapore's energy storage development. Singapore's Agency for Science, Technology and Research (A*STAR) recently signed an agreement with Canada's Hydro-Quebec to establish a joint laboratory to

research emerging battery technologies for electric vehicles and energy storage. In addition, the German company VDE set up a Global Energy Storage Competence Cluster (GECC) in partnership with Singapore's Nanyang Technological University.

4.2.2 Regional markets for energy storage

Both countries, as export-oriented economies, are often considered gateways to Europe (Estonia) and Asia (SEA and China) (Singapore) [43]. Both regions have strong potential as markets for energy storage solutions in the future. Despite a lack of immediate focus on energy storage domestically in Estonia, the country is motivated to fund R&D and develop capacity in energy technology priorities for the European Union (EU), one of which is energy storage [34]. In fact, many Estonian energy startups take advantage of EU R&D money through programs such as Horizon 2020 funding. The EU has a stated focus on energy storage solutions and a growing need for flexibility in the energy system, which would benefit from innovation in emerging storage solutions. The EU promotes battery storage technologies through its Horizon 2020 program and also has a specific program focused on fuel cells and hydrogen development [44]. According to the European Market Monitor on Energy Storage, Europe's energy storage market grew by 49% in 2017 [45].

While grid operators in Europe still have not fully defined the best way to integrate energy storage into their business models, the UK and Germany are currently the largest markets for energy storage in Europe, with favorable policies and regulations that provide flexibility to adjust to a quickly changing market. As more customers adopt storage technologies and costs start to go down, behind-the-meter energy storage is also seeing growth, with commercial and industrial (C&I) expected to grow 45% in 2018, and was recently dubbed the most exciting segment of the European energy storage market [45]. In the C&I sector, for example, there is a lot more flexibility to use energy storage solutions that provide resilience and independence in a company's energy generation, which impacts a business' bottom line and de-risks its energy costs by not fully relying on merchant revenues of short-term grid services contracts [45]. Innovative business models, such as storage-as-a-service, are also emerging, which will make access to energy storage easier and simpler for customers and grow customer demand for energy storage-as-a-service providers.

In SEA, frequent brown outs provide a strong incentive for the reliability that renewables-plus-storage, specifically solar-plus-storage, could provide [46]. While the regulatory environment in SEA is not currently friendly to renewables-plus-storage solutions, Singapore provides the perfect opportunity to act as both a technology and regulatory testbed for future deployment in SEA countries. Currently in the Asia-Pacific region, there is 1784 MW of energy storage system capacity in the pipeline, primarily from pumped hydro [47]. The remaining battery solutions are primarily lithium ion storage projects based in the Philippines and China. The lack of a more cohesive set of regional market mechanisms and policies in the SEA region indicates there is an opportunity for Singapore to take the lead in the energy storage sector. In addition, due to regulatory barriers in other countries, Singapore can also use its regulatory sandbox as a model for other SEA countries who are interested in R&D, demonstration and deployment of energy storage technologies.

Projected energy storage deployments by market show significant growth over the next 6 years in the East Asia & Pacific, signaling room for additional R&D and innovation in energy storage technologies. Increased focus on storage is evident in the growth of initiatives such as the ASEAN Solar + Energy Storage Congress and

Expo, which will bring together developers and investors to establish a sustainable and viable business model in SEA to prepare for the future energy transition [48].

4.2.3 Why Estonia and Singapore?

Significant focus on intermittent renewable energies (wind in Estonia, solar in Singapore) in both countries' futures provides a catalyst for energy storage R&D both domestically and regionally. The two countries have separate, but similar concerns regarding current and future energy security and dependence on neighboring countries as their shares of renewable energy grows. Domestic and regional market mechanisms, such as climate and renewable targets and policies, drive a need for innovation in energy storage and energy technology in general. While Estonia is looking to reduce its energy intensity, it's not concerned in the near-term with deploying energy storage domestically for energy security purposes. By participating in joint technology innovation with Singapore, Estonia can start preparing for a future that will most likely require some form of energy storage to ensure energy independence.

Together, Singapore and Estonia can provide each other with significant development opportunities and access to regional markets by leveraging each other's strengths and resources to jointly conduct energy storage R&D. Both countries rank fairly highly in entrepreneurship, innovation, and development indicators, such as ease of doing business, enabling trade, and the global competition, innovation and entrepreneurship indices. For example, Estonia's e-residency program and Enterprise Estonia office in Singapore, along with other key stakeholders can facilitate collaboration, while convenient access to regional markets can attract potential funding sources for joint collaboration. In addition, Estonia's recent presidency of the Council of the EU in 2017 provides it with the political know-how and relationships that Estonia can employ to help Singapore navigate Europe's policy and regulations [49].

In addition, as small countries rooted in knowledge economies, both countries have energy technology R&D systems and regulatory structures that can foster innovation and growth in the energy storage innovation pipeline. Estonia's energy storage R&D capabilities tend to be in the technical capabilities present in universities, startups, and the private sector, primarily focused on export, whereas Singapore's energy storage R&D is focused on the application of technologies in its government sponsored testbed, along with select international cooperation agreements between governments and university organizations. The alignment of technical focus and scientific capabilities of Estonia and Singapore in combination with the ability to rapidly implement potential storage solutions in the Singapore testbed complement each other in developing energy storage solutions. Such solutions not only serve to support both wind and solar technologies but may, as well, find application with other diverse energy generation technologies being explored in the testbed. Successful technology demonstrations resulting from the Estonian-Singapore collaboration may find ready funding for commercial scale-up through Estonia's access to EU funding, domestic venture capital funding, and startup culture and result in the desired creation of energy storage capacity and expertise.

4.3 Proposal for joint energy storage innovation collaboration

This section will outline the proposed joint collaboration between Estonia and Singapore on energy storage innovation by first laying out a proposed plan including key 'areas of interest' within energy storage and define key stakeholders.

Second, it will identify market mechanisms across both countries and propose an IP sharing cross-license model for the collaboration.

4.3.1 Proposed joint collaboration model

Given the interest in both countries for innovation in energy, the incentive to peruse energy storage, and opportunities for a mutually beneficial partnership as outlined in the above section, we propose Estonia and Singapore establish an initial joint collaboration, jointly led by Tehnopol Science & Technology Park in Estonia and Singapore's Agency for Science, Technology and Research (A*STAR). These two entities are involved in all stages of the innovation pipeline, which will help ensure smooth handoffs and mitigate the risks of 'valley of death' between the innovation stages. Both entities receive government funding, and should work with their respective government energy R&D departments to allocate existing funding specifically to begin this collaboration. Other stakeholders, such as Enterprise Estonia, Enterprise Singapore, the National Research Council of Estonia, and the Energy Market Authority in Singapore, can play key supporting roles.

The two organizations will collaborate to identify a joint development program with a realistic roadmap and solicitation process to both receive promising joint R&D collaboration research proposals and define opportunities to demonstrate, deploy and commercialize existing energy storage innovations, all of which will tie into the joint innovation pipeline. While initial funding will come from the two entities and ultimately government funds, Tehnopol and A*STAR will also help procure funding from any of the key stakeholders, such as the EU's Horizon 2020 fund, Estonian venture capitalists, or Singaporean government entities. The two entities will also be supported by resources from both sides, such as supporting mentorship and commercialization and market opportunities that are identified from each countries' respective enterprise and business development offices. For example, promising products or startups that come out of the joint collaboration could be candidates for inclusion in Tehnopol's startup incubator or use Singapore's ESS testbed to test product capabilities.

The joint collaboration will include four main components to accelerate successful development:

1. Creation of the Singapore-Estonia Energy Storage Collaboration Initiative (SEES-CI) (see **Figure 1**), which will focus on bringing together Singaporean and Estonian startups, university research institutes, and government R&D programs focused on energy storage technologies in both Estonia and Singapore.

    - The Initiative will be housed within a new Singapore-Estonia office for Energy Storage Collaboration in Tehnopol, the Baltic region's largest science and technology park, based in Tallinn. This office can eventually house an Enterprise Singapore office and serve as the country's Baltic and North/Eastern European headquarters, where it currently has no presence [50].

    - The SEES-CI will plan up front for success, so that IP cross-license agreements and commercial out-licenses and in-licenses necessary to commercial success of the initiative will be anticipated up-front and managed collaboratively by Enterprise Estonia and Enterprise Singapore (see section on Intellectual Property Sharing Model for Joint Energy Storage Technology Innovation).

2. Host an Annual Singapore-Estonia Energy Storage Expo & Workshop (alternately hosted each year) to interact and establish more defined areas for energy

research and innovation, as well as identify opportunities for demonstration in testbeds in either country, and identify commercialization/market opportunities and supply chain development throughout Europe and/or Southeast Asia.

- One outcome of the annual workshop would be to identify business delegations that could visit the other country, sponsored by Enterprise Estonia and Enterprise Singapore. The delegation visits would include visiting key stakeholders, including universities, R&D centers, startups, demonstration sites, and energy storage related government departments.

- The annual workshop could also serve as the kick-off event for the next annual round of requests for proposals solicited by the SEES-CI, in particular the call for joint R&D proposals noted as key element 4 below.

3. Establish a Resource Sharing Agreement in which Estonia and Singapore agree to share non-financial resources that enable energy technology development and clearly define these resources and who and how the resources will be applied consistent with the CEES-CI program. 'Resources' could include limited access to Singapore's ESS for demonstration, mentorship and SME time, laboratory researchers and materials, etc.

4. Call for joint R&D proposals between Estonia and Singapore in key 'areas of interest' related to energy storage. The proposals would require plans for demonstration and deployment, as well as a market analysis. Funding for these proposals could be set up with initial funding from both governments, with the potential for additional grants or funding from other sources such as the EU Horizon 2020 fund, Tehnopol, or other key stakeholders. The first three proposed 'areas of interest' include:

   - Hybrid Energy Storage Solutions (HESS)

   - Hydrogen Energy Storage and Fuel Cells

   - Supercapacitors

4.3.2 Key stakeholders and collaborators

The key energy innovation stakeholders in a joint energy storage innovation collaboration between Singapore and Estonia will include government organizations, universities, companies and startups, industry organizations, and regional institutions.

4.3.2.1 Government organizations

The primary government organizations involved in joint energy technology innovation and energy storage technology is the Ministry of Trade and Industry and Ministry of Foreign Affairs in Singapore and the Ministry of Economic Affairs and Communication and Ministry of Education and Science in Estonia. In this joint collaboration scheme, we propose that A*STAR, which falls under Singapore's Ministry of Trade and Industry and considers itself a 'catalyst, enabler and convener of significant research initiatives among the research community in Singapore and beyond' to co-lead the innovation collaboration with Tehnopol Science & Technology Park in Tallinn, Estonia [51].

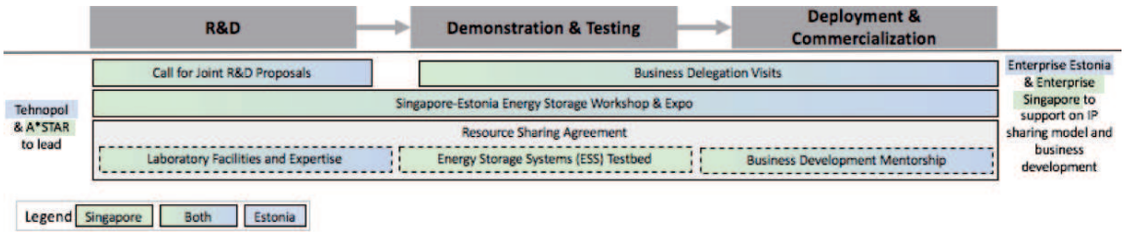

Figure 1.
Proposed Singapore-Estonia energy storage collaboration initiative (created by author).

Tehnopol is a research and business science park that includes a startup incubator and is a public-private-partnership (PPP) that receives funding from the city of Tallinn, Tallinn Technical University (TTU), and the central government of Estonia [34, 52]. Tehnopol has three main stages of support: (1) Prototron Fund, which is seed funding for an idea and without requiring equity from any future startup or business; (2) startup incubator with mentorship network and guidance; and, (3) business development and export assistance for companies with mature products [34]. Tehnopol often works to identify university research teams developing valuable technology, and begins mentoring them through the Prototron Fund, which can lead to establishing a startup.

These two institutions, A*STAR and Tehnopol are both focused on developing the full innovation pipeline with public and private partners, which will allow them to be creative in identifying joint collaboration opportunities and leverage partnerships across the full spectrum of stakeholders. Thus, they will be able to make connections between more R&D focused organizations such as universities, the ESS test bed and Estonian research council and organizations focused more on business development, such as Enterprise Estonia and Enterprise Singapore.

Each of these entities have vested interests in identifying business, innovation, and talent opportunities that drive R&D, innovation and commercialization within their respective countries–and will be able to do the same through joint collaboration.

4.3.2.2 Universities

Estonia and Singapore have strong tertiary education, with the Innovation Index ranking Singapore 1st and Estonia 27th out of 126 countries [53]. Each country has a few main universities that focus on science, technology and energy research, and are eligible for funding for research grants within the state and regionally. In Estonia, each of the universities identified in the stakeholder map have energy related programs. In addition, university R&D has a pathway to further develop its prototypes, through Tehnopol or its strong culture of startups and venture capital. With the shared TTU and Tehnopol campus, researchers at TTU have an opportunity to work with startups and entrepreneurs to further explore their idea. In addition, Tehnopol often serves as a 'testbed' for its members' technologies, such as a pizza-delivering robot and solar energy street lights [34]. They are also eligible to apply for research grants from the Estonian Research Council and other regional EU funds, such as Horizon 2020 funding.

In Singapore, each major university has a program or research focused on energy and on energy storage in particular, and are eligible to apply for funding for A*STAR or EMA's call for research proposals. In fact, the National University of Singapore and Nanyang Technological University and will be launching a Singapore Energy Center in partnership with ExxonMobil in early 2019 to explore innovative ideas and develop talent to meet future energy needs in Asia Pacific [54].

4.3.2.3 Companies and startups

In energy storage technology, a few key startups in each country could be key elements in a Singapore-Estonia collaboration. Through joint collaboration, they could further R&D on their projects, test innovations in the ESS testbed or other demonstration sites, or deploy their products to new markets. For example, SkeletonTech, an Estonian supercapacitor startup, originally received funding from an Estonian-Norwegian joint energy technology innovation program in 2013 and has received at least one round of venture capital funding [25]. However, it is focused primarily on the European market, and could use the Singapore-Estonia joint innovation program as an opportunity to explore new markets and test its technologies in Singapore's climate.

4.3.2.4 Industry organizations

The industry organizations in Estonia and Singapore are focused mostly on renewable energy, with one industry organization in Estonia focused on hydrogen energy. These associations can play a role in helping advocate for regulatory and policy mechanisms that will promote renewable energy and ultimately energy storage and also work with organizations such as Enterprise Singapore and Enterprise Estonia in developing a strong community of partners within each country. As renewable energy becomes more prevalent in both countries, industry organizations will become more and more important for building up skills capacity in energy storage.

4.3.2.5 Regional institutions

As primarily export markets, both Singapore and Estonia have interests in exporting energy technologies to the Southeast Asian and European markets. Both regions host large energy storage conferences, which bring together startups, researchers, government officials, and experts, and could be a good way to advance opportunities between an Estonia and Singapore cooperation. In Asia, the Asia Energy Storage Association was recently founded in August 2018 and aims to be a regional platform for all energy storage industry stakeholders to promote the best interests of the energy storage sector in Asia [55].

The ASEAN Energy Business Forum brings together Ministers of Energy from ASEAN countries to identify business opportunities in the region. However, currently most energy storage research and demonstration in the region is on a country by country basis, with little clear research funding from a regional perspective (ASEAN or otherwise) [56]. In Europe, funds such as Horizon2020 and PowerUp! have been a crucial part in advancing Europe's energy priorities, including energy storage. Europe also separates hydrogen and fuel cell research from its other energy storage goals, and has separate funding in both areas as well.

4.4 Market mechanisms for energy storage in Singapore and Estonia

This section will discuss how market mechanisms for energy storage will be divided between Singapore, Estonia and the EU. While the SEA region has very little regional funding or policies to support energy storage, Singapore can help lead the efforts in identifying key country markets in SEA in the absence of a more cohesive regional market mechanism.

Because both countries are relatively small in population and area, neither country will be able to sustain a market on its own for any given technology.

However, Estonia and Singapore, respectively, have still maintained levels of R&D capacity, skills development and capacity building, and innovation by leveraging their positions as "gateways" to Europe and Southeast Asia. Both countries also have strong abilities to export high-tech products and services [57]. Singapore especially has become a key location for joint collaboration in energy technology, and more recently energy storage technology [38].

The below chart (**Figure 2**) outlines the major market push and pull mechanisms in Singapore, Estonia, and the EU. From a SEA perspective, while the market for energy storage has the potential for extreme growth, the region does not have any cohesive mechanisms (policies, funding, etc.) that provide pull or push for energy storage. However, individual countries such as the Philippines, do have market demand for energy storage technologies, and new forums such as the ASEAN Solar + Energy Storage Congress and Expo will start to identify deployment opportunities in the SEA market. Together, these policies, funds, and market demand, combined with the innovation pipeline and stakeholder structure in Estonia, Singapore, and the EU provide a model for success in Estonian-Singaporean energy storage collaboration.

4.4.1 Market push

From a funding & services perspective, both countries as well as the EU offer funding opportunities to conduct R&D activities related to energy storage through programs such as the Estonian Research Council Grants, Horizon 2020 funding, and A*STAR grants and funding. For example, the EU's program on Accelerating Clean Energy Innovation plans to deploy €2 billion towards its priority R&D areas, one of which is 'developing affordable and integrated energy storage.' [58] The EU Emission Trading Scheme (ETS) Innovation Fund was created in 2015 and creates a fund from ETS revenues to support large-scale demonstration of energy innovation, including energy storage [59]. In addition, Singapore's Energy Storage Program, which includes the ESS testbed initiative, and Estonia's Tehnopol Science & Technology park, offer programs such as the Prototron Fund and Startup Incubator that will push R&D in energy storage sector.

One interesting item to note is that both Singapore and Estonia had formal energy technology innovation programs and funding, but did not renew them

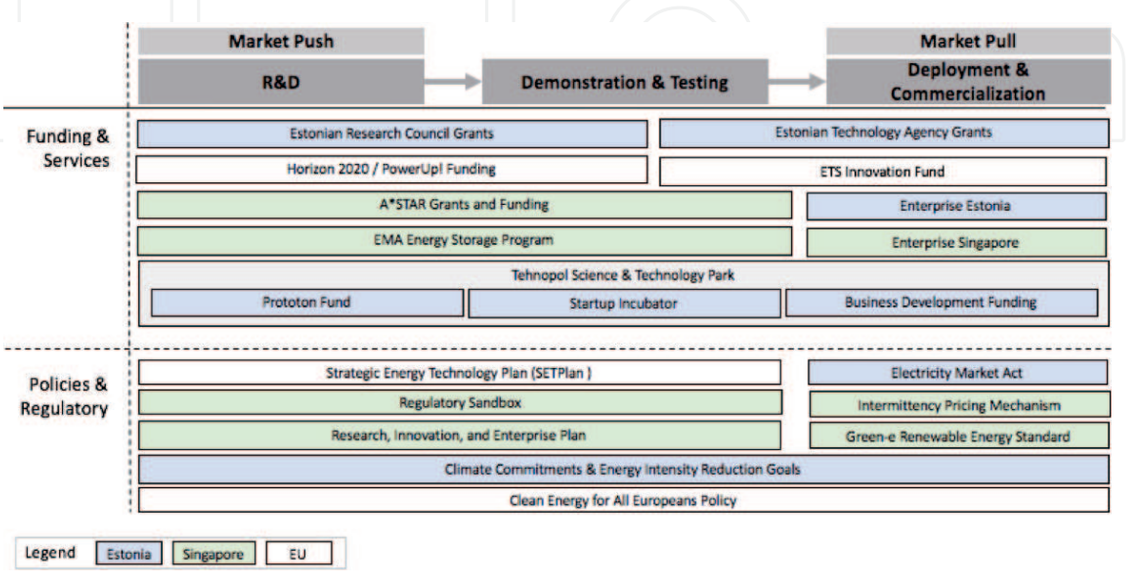

Figure 2.
Market push and pull for energy storage technology in Estonia, Singapore, and the EU (Created by author).

after their five-year periods. Singapore had an Energy Innovation Program Office (EIPO), which is no longer in operation, and allocated S$195 million from the National Research Foundation to promote R&D in the energy sector from 2010 to 2015 [60]. The Estonian Energy Technology Program also had €6.5–9.5 million allocated from 2008 to 2013, which supported R&D, technology transfer, and joint activities and value added services [44]. With neither of these mechanisms in place anymore, both countries will have to leverage alternative sources of funding.

In the policy and regulatory space, Singapore provides more mechanisms to encourage R&D and deployment & commercialization of energy storage technology. For example, Singapore's regulatory sandbox provides impetus to innovate and test out new technologies without the risk of regulatory barriers. In addition, its Research, Innovation and Enterprise Plan has set aside $275 million USD for key research, development and deployment initiatives in the energy space, focusing on areas such as solar, energy storage, smart grids, and green buildings [40]. Singapore is also planning to implement a carbon tax by 2025, which could provide revenue that will induce additional innovation in low carbon energy technologies and energy storage [61]. In Estonia, its Estonian National Development Plan of the Energy Sector for 2030 (ENMAK 2030+) and climate policy principles for 2050 (KPP) incorporate climate commitments as part of the EU's Paris Accord commitments, energy intensity reduction goals, and a shift away from shale power generation to wind and renewables [37]. These factors combined with a future concern for energy security and lack of large-scale storage solutions to address intermittency of renewables will help push energy storage R&D. Finally, the EU's Strategic Energy Technology Plan, which focuses on accelerating development of energy technologies, along with the Clean Energy for All Europeans package, which proposes EU policies and standards on several aspects of energy including renewables, efficiency, and electricity markets, will both provide regulatory certainty and encourage essential investments into the energy storage sector [62, 63].

4.4.2 Market pull

From a funding & services perspective, the Estonian Technology Agency provides grants that assist in the piloting and deployment of new technologies. Tehnopol also provides business development funding and assistance. Finally, Enterprise Estonia and Enterprise Singapore, which are business development organizations in each country, promote business and regional policy and are critical parts of their respective national support systems for entrepreneurship and product commercialization. They also provide training opportunities and connect public sector, research institutions and private enterprise to help commercialize products in export markets [64].

In the policy and regulatory space, the EU's Clean Energy for All Europeans package provides binding standards on renewables and greenhouse gas emission reductions that will help create market pull (and push) for energy storage technologies. Estonia's climate policy as mentioned in the market push section, such as its commitment to reduce energy intensity and shut down shale energy generation plants, could also create a market pull for energy storage. Estonia also recently passed the Electricity Market Act, which introduces technology-neutral auctions for renewable energy projects, includes a clause that states that the Competition Authority can impose obligations to invite tenders for energy storage devices [65]. Singapore recently announced an intermittency pricing mechanism (IPM) that will require reserves to be available to ensure stability of supply and could be a significant market pull to deploy energy storage solutions in Singapore's grid [29]. Finally, Singapore's Green-e Renewable Energy Standard (RES) certifies renewable energy

products and aims to accelerate renewable electricity markets and develop a mechanism through which consumers can demand renewable electricity. This policy could also increase demand for energy storage to mitigate intermittency [66].

4.5 Intellectual property sharing model for joint energy storage technology innovation

With regard to intellectual property (IP), Singapore has a somewhat stronger IP and innovation rating while Estonia is somewhat weaker in this area. It is especially important for the joint proposal to outline how IP created in the technical collaboration will be shared to mitigate risks associated with jointly sharing IP rights and provide the fairest model [67]. Both Singapore and Estonia have know-how related to their respective regional markets and policies that can help leverage the collaboration on IP and guide the introduction of successful technologies into nearby SEA and European markets, respectively.

It is proposed that, consistent with commercial collaborations, Singapore and Estonia agree at the outset to a royalty-free cross-license of the intellectual property developed in collaboration–free for each country to deploy in their respective countries plus a sharing of returns on such intellectual property if licensed outside their countries. This mutual commitment would encourage the two countries to provide the complementary technical, financial and management resources needed for success. Such intellectual property collaboration is enhanced by the geographic separation of Singapore and Estonia which limits concerns about competition between their economies.

To encourage company, start-up and university participation, the SEES-CI would require that before third-party technology is used in the collaboration by a country, the third-party licenses or makes available its technology for such collaborative research activities and commits, if requested, to non-exclusively license its IP on commercially reasonable terms and conditions through the organization chosen by Estonia and Singapore to commercialize the collaboration IP outside their borders [68].

Cross-licensing between Estonia and Singapore and the promise of commercial licenses are a priori commitments that will short-cut the win-lose thinking that otherwise dominates many collaborations, where the focus is misplaced from desired outcomes and drifts to questions about sole or joint inventorship, and the withholding of ideas arising from concern over legal rights. Rather, it is intended to foster true collaboration and the free flow of ideas.

For intellectual property to qualify as falling under the joint cooperation program, the SEES-CI must have agreed to the project proposal and provided some of the funding as part of SEES-CI, and have agreed to the scope of work and the deliverables of the project. This will make clear the scope of technology to be captured under the agreement and that will be cross-licensed to Estonia and Singapore, and available through the organization chosen by Estonia and Singapore to commercialize the collaboration IP outside their borders.

Key individuals from each country from the designated institutions may also be identified and would be expected to exhibit the leadership and integrity to accurately manage the disclosure of contributions to the development and innovation process in performance of projects under the collaboration, which could include: conception of ideas; material contributions to the development of an invention, data, information, software, hardware or trade secrets; providing solutions or troubleshooting to problems; implementing the invention; and/or providing ordinary assistance, such as performing routine tasks or executing testing. All depends on SEES-CI managing defined tasks and responsibilities assigned to each country in a fully thought-out roadmap of funding and technology development,

implemented through a series of projects performed by government, university and private stakeholders.

Singapore and Estonia will be responsible for patenting the technology in their respective countries and can in the course of defining the collaboration, determine details of cross-licensing as previously discussed, or decide to proceed as co-owners of the patents [69]. All costs related to filing, renewal and prosecution fees related to the IP will be shared equally. Where private research efforts, universities, or non-government laboratories are part of the collaboration on behalf of Singapore or Estonia, the countries may wish to adopt an approach much like the Bayh-Dole rights in the United States, under which the funding government receives non-exclusive rights which may be shared with the other collaborating country, and the non-governmental collaborating entity may elect to pursue IP protection for commercialization [70].

As between Estonia and Singapore, a commercial-like arrangement can be adopted should one country wish to file for patent protection in a country where the other does not (i.e. if Singapore wants to file in China and Estonia does not), the other party will have the right to file and maintain the patent or patent application at its own expense. In that case, the non-participating country would not share in any income from the country where they do not support or withdraw support of the patent costs [43].

It is proposed that Estonia and Singapore agree to license collaboration intellectual property outside their countries through a single entity acting on their behalf who could also bundle any enabling privately held IP rights into a licensing package. Regardless, as is typical, no obligation would exist to share licensing income for pre-existing background intellectual property or inventions that are developed outside the collaboration, except as may be agreed.

Patent enforcement strategies will also be agreed upon as part of the collaboration. Should a dispute arise between Singapore and Estonia that cannot be resolved by mutual agreement of parties, the parties would decide to work with the World Intellectual Property Organization or another international body they may designate to determine the correct course of action for arbitration and mediation [71].

As business development institutions, Enterprise Estonia and Enterprise Singapore can work with Tehnopol and A*STAR to help monitor the IP sharing agreement and help identify appropriate markets for deployment and commercialization. By allowing the Enterprise arms of Singapore and Estonia to lead the IP sharing agreement, both entities will be motivated to not only ensure proper protection of innovation, but also ensure fair and transparent IP sharing agreements within the two countries and internationally.

5. Conclusions

With environmental challenges increasingly becoming global challenges that transcend boundaries, so too will opportunities for joint collaboration in energy innovation. In the words of Louis Pasteur, "Science knows no country, because knowledge belongs to humanity, and is the torch which illuminates the world [72]." As international collaboration continues to grow within the context of a more globalized system of science and innovation, the role for small country joint collaboration will grow stronger.

Small country joint innovation can help address some of the unique challenges that small countries face and develop balanced and mutually beneficial collaboration. This paper discusses challenges, criteria, benefits, and enablers for successful small country joint innovation. Together, small countries can leverage each other's strengths to build successful and creative models of innovation collaboration. These

models can be valuable for countries big and small, developed and developing, and provide one more tool for combating energy issues around the world. A proposed joint collaboration between Singapore and Estonia presents a model for energy storage technology, that, if successful, could continue to evolve, leading to increasing opportunity for win-win collaboration across a spectrum of energy opportunities.

While the case study in this paper uses energy storage technology as a basis for small country joint innovation, storage is just one of a suite of potential innovations that a small country could pursue to make choices around energy investments. Depending on a given country's energy needs, access to investment, and innovation capabilities, energy technologies such as solar PV, energy storage, fuel cells, geothermal, wind, biomass and biofuels are all additional areas in which small country could pursue joint innovation. Innovation in these areas can drive decisions around investments in additional areas such as grid management software and energy infrastructure, which can eventually lead to development at scale and a replicable model for other countries.

In addition, the opportunity for small and large country innovation can be further enhanced by 'polycentric innovation.' The idea of polycentric innovation, which consists of shared networks of international talent, capital, and ideas that initially take advantage of regional opportunities and are then integrated into global innovation networks, can be an important concept for small country joint innovation [73]. To enhance policy effectiveness in institutional development and optimize processes, Nyangon & Byrne (2018) and Liu & Liu (2018) argue that nations should mainstream polycentric innovation at multiscale levels to advance greater technological innovation ecosystem, customer enterprises, and business model innovation [74, 75].

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