European Commission

EU Research and innovation and the invasion of Ukraine

Main channels of impact

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Research and Innovation

European Research and innovation and the invasion of Ukraine: Main Channels of impact

European Commission
Directorate-General for Research and Innovation
Directorate G — Common Policy Centre
Unit G.1— Common R&I strategy and foresight service

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Working paper

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TABLE OF CONTENTS

ABSTRACT

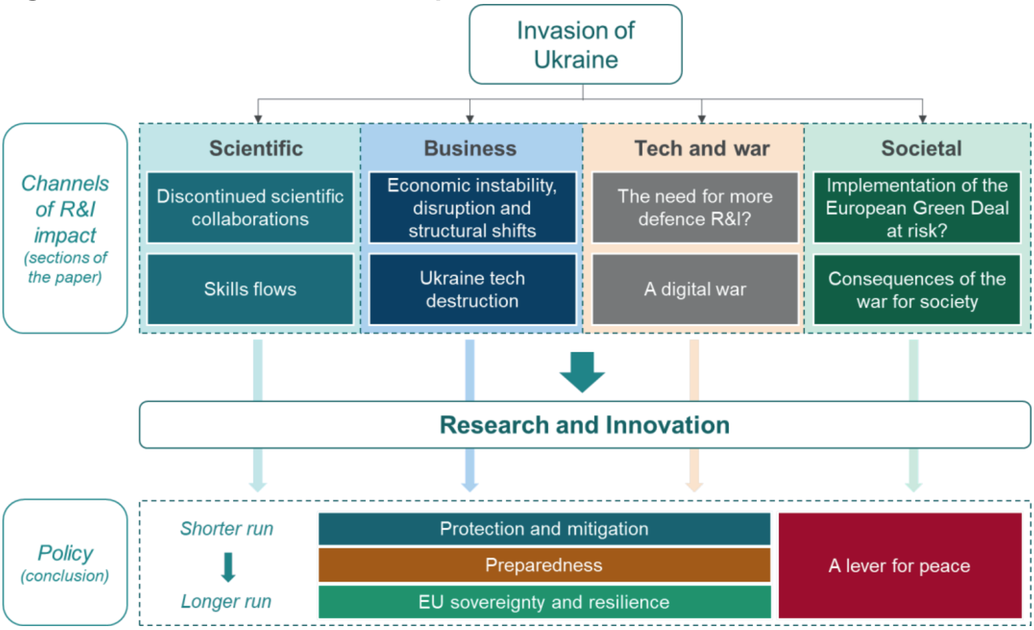
This paper aims to identify and investigate the impact of the invasion of Ukraine by Russia in early 2022 on research and innovation (R&I) in Europe. The war itself, together with associated sanctions, migration flows, unstable economic environment, supply chain disruptions and energy dependencies, affects EU R&I through several channels, ranging from scientific collaboration and availability of researchers to economic implications for businesses, progress in green transition, social impact, and increased demand for defence and security. The conflict has both short- and longer-run implications for policy. In the short run, expected disruptions call for protection and mitigation measures. In the medium to longer term, as for the COVID-19 crisis, the conflict underlines that Europe needs preparedness as well as reinforced resilience and a reconsideration of EU dependencies. R&I can also be seen as a lever for peace, being at the basis of sustainable socioeconomic development and therefore peaceful societies.

1 Introduction[1]

Russia launched the invasion of Ukraine in February 2022. While the outcome is still uncertain at the time of drafting this paper, the damage done by the war is already immense and the invasion is expected to have significant **implications for the years to come in Europe**. EU leaders strongly condemned the invasion and the EU has progressively introduced packages of sanctions against Russia[1], including restrictions on economic and trade relations, on access to capital, on financial transactions, frozen assets and airspace ban. At the same time, the EU has provided coordinated humanitarian, political, financial and material support to Ukraine. The conflict and associated sanctions are expected to severely impact the global economy, via trade disruptions, inflation induced by rapidly increasing energy, food and other commodity prices and turmoil in financial markets. Countries with close economic links to Ukraine and Russia are particularly exposed to severe supply disruptions and are most affected by the inflows of refugees. A particular issue for Europe is its reliance on Russian gas.

[1] We thank Athina Karvounaraki and Tiago Pereira for their contribution on indicators, as well as Julien Guerrier, Peter Droell, Nelly Bruno, Massimiliano Esposito, Alberto Domini, Simone Rosini and Philippe Tulkens for their feedback on the paper.

Figure 1. Main channels of R&I impact of the invasion of Ukraine



Source: Authors' elaboration.

This paper aims to identify and investigate the **channels through which the conflict affects research and innovation (R&I) in Europe** ('channels of R&I impact', see Figure 1).

At the time of writing, there is high uncertainty about how and when the conflict will be resolved. Irrespective of the eventual scenario that will materialise, it is clear that the political, economic and social implications of the conflict will be profound and will also affect the EU and the world at large. At this moment, it is far too early to gauge with any degree of certainty the impact of the war. Nevertheless, it is possible to identify the main channels through which these implications will manifest themselves. Many of these channels will have a **direct or indirect impact on R&I**. Their importance will vary over time with the most direct ones due to the sanctions and economic disruptions dominating in the short-run, while more structural channels and those related to adjustments in policies, e.g. defence or energy, as well as social and political preferences will become increasingly important in the medium- to long-run.

Many of the implications of the war will have an impact on EU R&I. The war is expected to have a direct impact on science (section 2) as it has severely disturbed collaboration with Ukraine and sanctions have put a stop on scientific collaborations with Russia and Belarus. Migration flows of skilled workers from Ukraine to the EU can also impact scientific production as well as innovation capacity more generally. Businesses (section 3) are affected by the unstable economic environment and disruption of supply chains, which may impact their R&I activities. At the same time, the war will negatively impact the vibrant tech ecosystem in Ukraine. The conflict also brings research and development (R&D) in defence and security to the centre stage (section 4). Finally, it raises crucial questions in relation to environmental and social aspects (section 5): clean energy technologies can be instrumental in alleviating existing energy dependencies, and R&I can play a role in mitigating the consequences of the war for society, which are expected to be pronounced. The paper concludes with policy implications for the short-run but also for the longer-run.

2 Impact on science

2.1 Discontinued scientific collaborations

Following the Russian invasion of Ukraine, **the European Commission has decided not to conclude any new contracts nor new agreements with Russian and Belarussian organisations under the EU R&I Framework Programme, Horizon Europe.** Furthermore, the Commission is suspending payments to Russian entities under existing contracts. All ongoing projects, in which Russian and Belarussian research organisations are participating, are being reviewed – both under Horizon Europe and Horizon 2020. At **national level**, some Western governments and organisations decided to isolate both countries scientifically, such as the Dutch knowledge institutions.[2] These developments raise the question of the expected impact of suspending R&I collaborations with Russia in particular. Furthermore, scientific collaboration with Ukraine is disrupted because of the war.

Russia is an important science, technology and innovation actor in the neighbourhood of the EU. Scientific relations with Russia have been historically strong, and are supported by a large network of scientists and scientific institutions, producing important achievements in diverse areas of science and their applications (European Commission, 2018a).

However, Russia is characterised by a relatively **low R&D intensity, low number of publications and patents per inhabitant, and heavy reliance on public funding for R&D activities** (Table 1 and Figure 2). In 2019, Russia dedicated 1.04% of its GDP to R&D activities, less than half of the EU or China (both at 2.23%) and even much less than the frontrunners such as USA, Japan or South Korea. Besides, this share has stagnated over the past two decades. When it comes to research output, Russia is also a rather modest actor with only 2.4% of world publications and 0.2% of the total patents filed under the PCT worldwide over the period 2000-2020. Only 1.7% of Russian publications are amongst the top 10% of highly cited publications, compared to 9.8% in the EU, 7.8% in China and 14.7% in the USA. Finally, most of the R&D efforts in Russia come from the public sector as businesses fund only 30% of the R&D expenditure, compared to more than 60% in the EU (Figure 2). Consequently, the impact of the war on R&D investments is uncertain: if economic sanctions against Russia affect mainly the private sector, R&D funds could experience only a minor decline, but if public resources

[2] https://universiteitenvannederland.nl/nl_NL/nieuwsbericht/nieuwsbericht/828-p-strong-nederlandse-kennisinstellingen-bevriezen-samenwerkingsverbanden-met-rusland-en-belarus-nbsp-strong-p.html

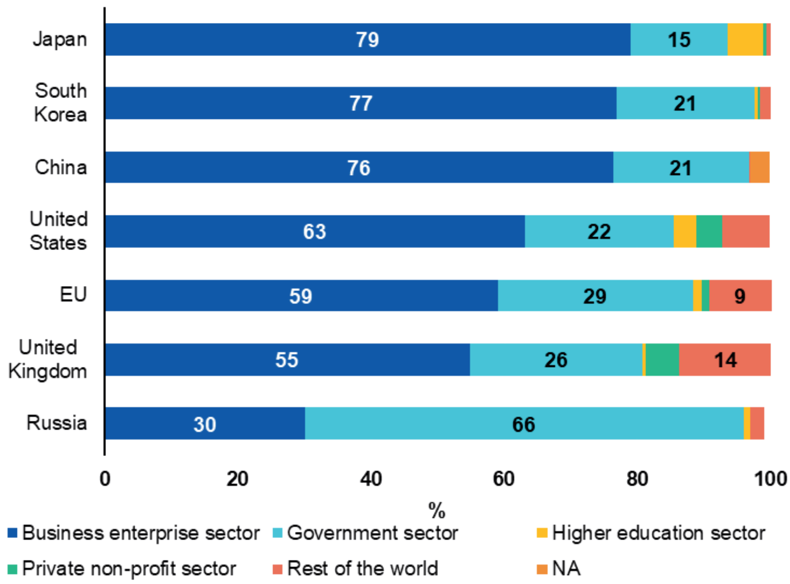
available become scarce, R&D investments and performance could decrease significantly.

Table 1. Main R&I indicators for Russia, China, the United States and the EU.

Indicator	Russia	USA	China	EU
R&D intensity (R&D investments as % of GDP) in 2019	1.04%	3.08%	2.23%	2.23%
Total publications 2000-2020	1,014,077	8,937,782	1,178,004	9,946,480
Publications per million inhabitants in 2020	680	1,493	500	1,379
World share of total publications 2000-2020	2.4%	21.1%	16.6%	23.4%
Average growth rate of scientific publications 2000-2020	6.0%	2.2%	12.9%	3.8%
% Highly cited publications (top 10%), 2000 - 2020	1.7%	14.7%	7.8%	9.8%
Inflow/outflow of researchers (2001-2020)	0.75	1.21	0.71	
PCT patent applications 2018 (fract. count)	1087	53,954	51,089	47,456
World share of PCT patent applications (fract. count) 2018	0.4%	22.0%	20.9%	19.4%

Source: Science-Metrix based on Scopus database

Figure 2. Percentage of gross domestic expenditures on R&D by source of funds of R&D investments per country or region, 2019



Source: Eurostat. Note: NA indicates amounts for which the source is not available.

Russian science is likely to be severely hit after scientific partnerships with the EU and other countries are discontinued. Although Russian researchers publish primarily with their national peers, 25% of their publications over the 2000-2020 period are the result of an international collaboration (Table 2). The share of international co-publications in Russia is higher than in Japan (23%) or in China (18%), meaning that their scientific community is more inclined to enter in international collaborations. Furthermore, **58% of the international co-publications of Russia are with EU researchers**. Almost no other country except the Eastern Partnership countries has such a preference for scientific collaboration with the EU. Also, as regards patent production, Russia tends to collaborate more internationally than the EU average (with respectively 19% and 12% of patent applications involving a foreign co-inventor), or the USA (13%). Besides, about 23% of the patents filed by Russia have a foreigner as co-inventor, including 13% of Europeans. Hence, **Russia relies more on international collaborations than other countries or regions**, such as the EU, the USA, Japan or China when it comes to scientific and technological production. Stopping collaboration in R&I may harm Russia's competitiveness in the long run. With the EU being a preferential partner of Russia on the R&I front, cutting the ties could be detrimental mainly to Russia in the short term, but **it can also impact both economies eventually.**

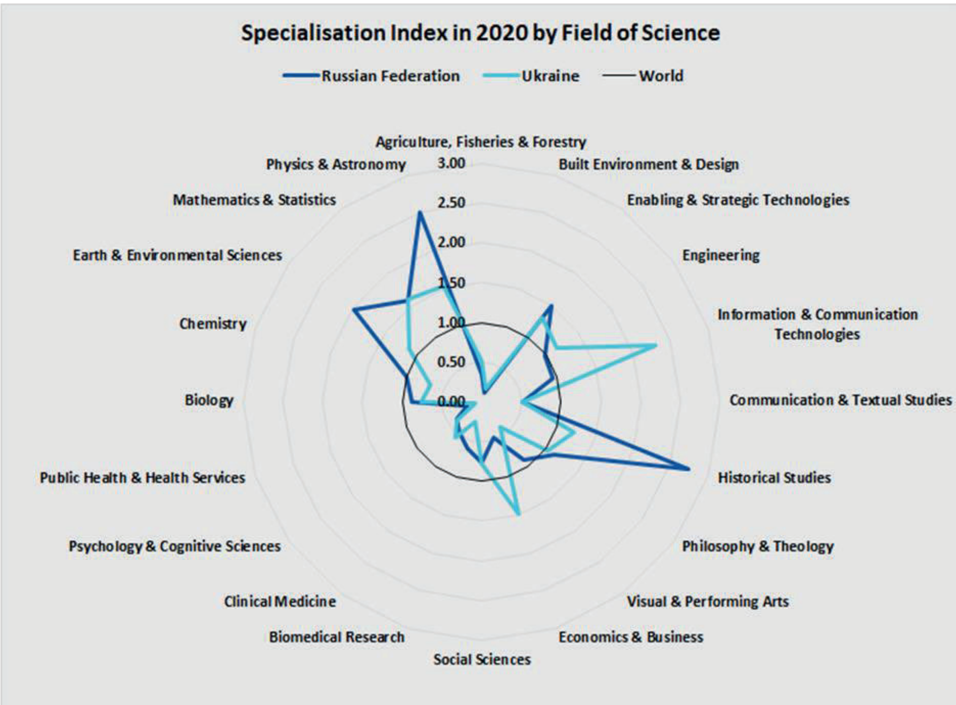
Table 2. Indicators of R&I collaborations between Russia and the EU

Indicator	Ukraine	Russia	EU
Share of international co-publications with the EU, 2000-2020 (over all international co-publications)	62.3%	57.7%	
Share of co-publications with the EU, 2000-2020 (over all co-publications, domestic and international)	21.6%	14.4%	
Share of international co-publications, 2000-2020	34.7%	25%	45.8%
Share of patents filed under the PCT with foreign co-inventor(s), 2019	---	18.9%	11.7%
Share of patents filed under the PCT with European co-inventor(s), 2019		5.1%	
Share of patents filed under the PCT owned by foreign residents, 2019		23.4%	13.3%
Share of patents filed under the PCT owned by European residents, 2019		5.0%	9.3%
Share of patents filed under the PCT and owned domestically invented abroad, 2019		7.2%	15.8%
Share of patents filed under the PCT and owned domestically invented in the EU, 2019		1.7%	10.1%

Source: Science–Metrix based on Scopus database and OECD (International co-operation in patents) data.
Notes: Patent Cooperation Treaty (PCT) patents, at the international phase designating the European Patent Office. Full counting method and priority date used.

Discontinuing collaboration with Russia could impact mainly research and innovation in the energy sector in the EU. Russia's research is mainly directed towards natural sciences, physics, astronomy and history. Russia has also higher world shares of patented inventions in chemistry - micro-structural and nanotechnology (1.2%), and mechanical engineering - engines, pumps, and turbines (1.3%).[3] Finally, Russia innovates mainly in the energy sector (3% of the world share) (Figure 3). As scientific cooperation is a powerful tool for both technology transfer and knowledge sharing, discontinuing scientific collaboration with a partner specialised in the energy sector may limit economies of scale in the corresponding research fields and the uptake of technologies in the energy sector in the EU. **But these effects may be limited for the EU economy** as Russia's world shares in terms of patents and publications are low for any given technology field (below 2%) and for any given field of science (below 3%) respectively (Table 1).

Figure 3. Specialisation index by field of science in Russia, 2020



Source: Science-Metrix based on Scopus database

The war also disrupts collaborations with Ukraine, a preferential partner of the EU in science. Ukrainian researchers are characterised by a high propensity to collaborate internationally: 35% of their publications are international co-publications and 62% of those are with EU researchers (Table 2). They specialise in the fields of Information and Communication, as well as Physics and Astronomy and Mathematics

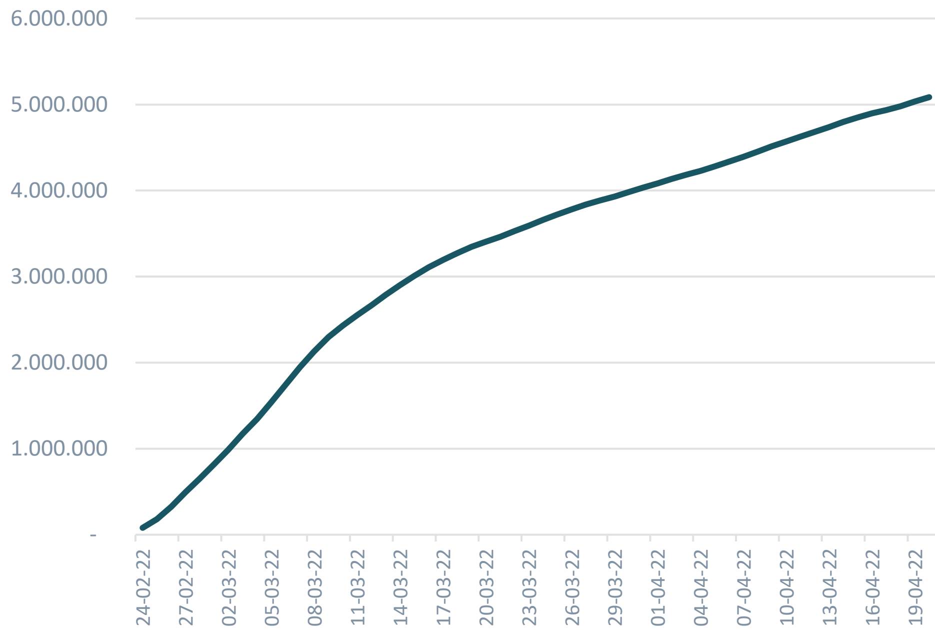
[3] Science Metrix based on Patstat data.

and Statistics (Figure 3). Ukrainians inventors are active in the fields of energy and transport and Ukraine's biggest shares in patent applications worldwide are in Environmental technology (0.25%), analysis of biological materials (0.22%), and special machinery (0.27%).[4]

2.2 Skills flows

By the 20th of April 2022, more than 5 million people left Ukraine, looking for refuge in the neighbouring countries (Figure 4), making it the largest group of refugees in Europe since World War II. Poland is the country with the highest refugee inflow, accounting on its own for around 2.8 million refugees (Figure 5). Such country-specific exodus ranks among the largest in modern history (1951-2021), with only Syria having experienced a larger refugee population running away from war (Figure 5).

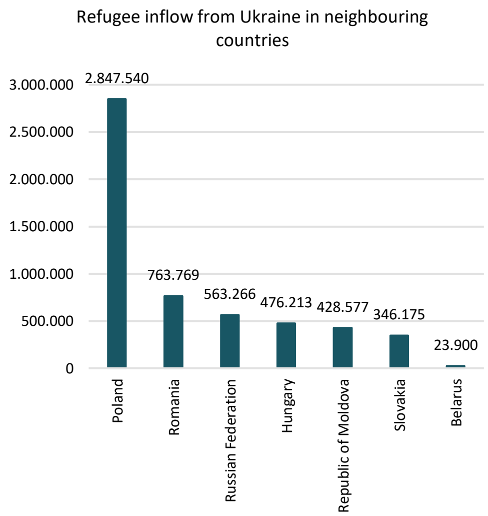
Figure 4. Ukraine refugees' trend

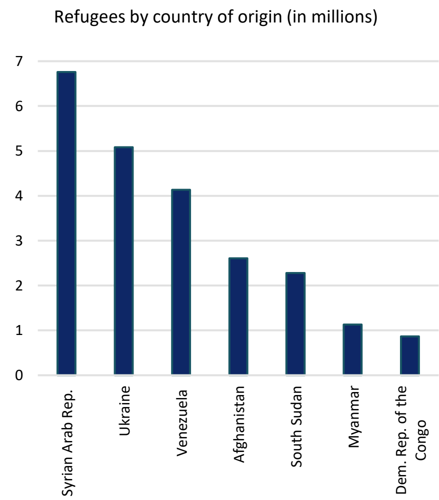


Source: UNHCR. Data downloaded 21/04/22. Data until 20/04/2022

[4] Science Metrix based on Patstat data.

Figure 5. Refugee inflow from Ukraine (left panel) and the Ukraine exodus in perspective to other exoduses in recent history (right panel)



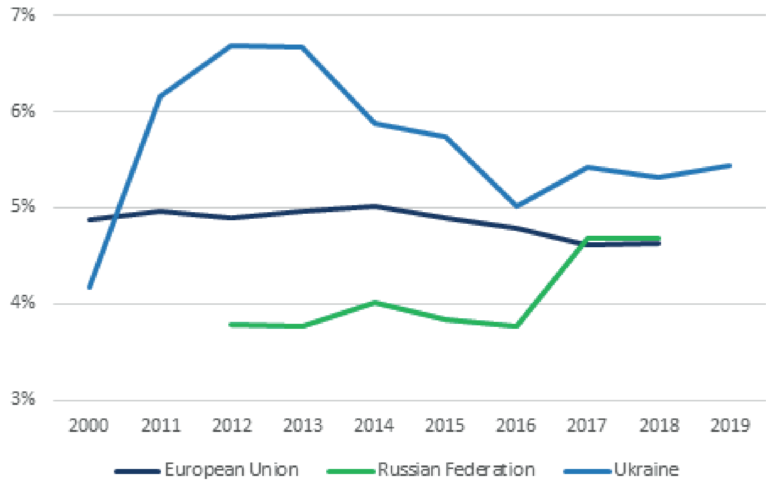


Source: UNHCR. "Refugee influx from Ukraine" data downloaded on 21/04/22. Data until 20/04/2022. "Refugees by country of origin" data downloaded on 21/04/22. Data on Syria, Venezuela, Afghanistan, South Sudan, Myanmar and Congo are updated from 1951 up until mid-2021. Data on Ukraine counting from February 2022 and updated up until 20 April 2022.

The Ukrainian refugees will have the right to live and work in the EU (with access to healthcare, housing and schooling) for at least one year[5], a period that will be automatically extended for a further year. If the displacement continues for years, it will present long-term challenges for both Ukraine and the hosting countries. Ukraine would face a brain drain of remarkable proportions, while host countries may see rising anti-immigrant sentiment, fuelled by resource scarcity. Yet, according to recent estimates of Goldman Sachs, the EU should be able to handle the financial implications of the exodus from Ukraine. In case of a refugee flow of 4 million Ukrainians to the EU, the associated financial support would be in the order of magnitude of 0.1-0.2% of GDP of the EU's four largest economies (Strauss, 2022). At the same time, the migration of an educated population could also bring benefits to the receiving European countries. Indeed, the Ukrainian population has a good level of education, with 79% of those aged 20-26 possessing a degree (The Economist, 2022a). Ukraine has a relatively high public expenditure on education (Figure 6), with rising school enrolment metrics, and non-irrelevant part of the population devoted to R&D activities (Figure 7).

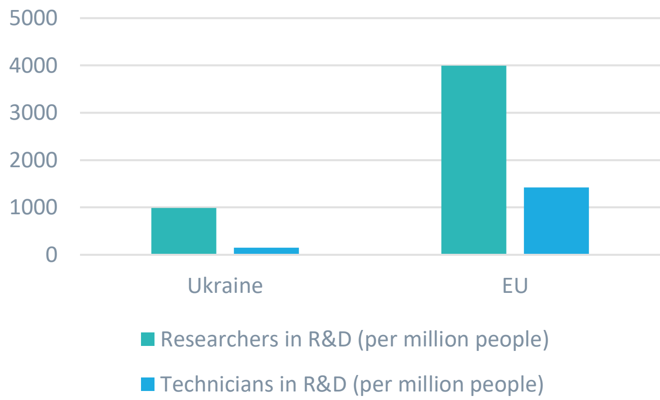
[5] So far, the Ukrainians migrating are mainly women and children. Ukrainian men aged 18-60 are subject to conscription and banned from leaving the country.

Figure 6. Government expenditure on education (% GDP)



Source: World Bank Database

Figure 7. R&D personnel in Ukraine



Source: World Bank Database. Data refers to 2018

Forced displacement of people due to conflict tends to be of longer term nature than natural disaster-related displacement, which is often a short term phenomenon. The longer people are away from their country of origin, the more likely they are to develop a new life, and the less likely they are to return home (Cook 2021). For this reason, it will be crucial to enact labour market policies and other measures to effectively integrate Ukraine migrants in the EU job market, aiming at filling skills gaps and shortages when possible. At the same time, if the fierce resistance by the Ukraine population prevails, and the Russian invaders are forced to retreat, it is likely that most refugees will want to go back home to start re-building their country. The support and hospitality from the EU to the returning Ukrainians may well be a founding element of future stronger and closer collaboration.

At the same time, with the deterioration of R&I collaborations between Russia and the rest of the world (see section 2.1), **highly-skilled emigration from Russia could also be an outcome of the war and contribute to scientific production in the EU.**

Russian brain drain is not a new phenomenon. For years, the country has faced mass emigration of highly trained and highly educated citizens to Europe and the USA. Since Vladimir Putin took office until 2019, around 2 million people have left Russia, many of which were researchers, entrepreneurs and artists (Herbst and Erofeev, 2019). With the unprovoked invasion of Ukraine, such exodus is likely to increase (Lalljee, 2022). Since the beginning of the conflict, thousands of Russians (particularly well-educated urban middle class) have already fled the country (Vasilyeva, 2022). To limit such outflow the Russian government has imposed travel restrictions such as the banishment of leaving the country with more than $10,000 in tow. As foreign academic institutions and foreign companies break off their relationships with Russian ones, many young talented Russians may decide to follow such institutions and companies outside of Russia. For the EU, attracting Russian brains can also be a way to boost EU innovative potential.

Immigration, especially skilled immigration, can raise innovation of the hosting countries. Researchers, technicians and scientists bring their ideas and skills, benefitting the innovative potential of the receiving countries.[6] Historically speaking, immigrants are over-represented among inventors and entrepreneurs. For example, Moser et al. (2014) show that the Nazi expulsions of Jewish scientists in the 1930s boosted innovation in American chemistry when they arrived. In the USA, immigrants account for 14% of the workforce, while accounting for 52% of STEM doctorates, a quarter of all patent-holders and a third of all US Nobel Prizes (Teichgraeber and Van Reenen, 2022).

3 Impact on (innovative) businesses

3.1 Economic instability, disruption and structural shifts

The escalation in the Russia-Ukraine conflict has shocked markets worldwide. The higher uncertainty produced by the increasing geopolitical tensions has increased the risk of investing in European assets. In addition, the increasing energy prices have pushed further up inflation expectations, while growth expectations have been lowered (Oppenheimer, 2022). Global financial markets have been taken by surprise by the Russian military attack, and had to quickly adapt their expectations to a fast-changing scenario, characterised by the interplay of several elements, e.g. the impact of the sanctions, the surge in commodity prices, and central banks' reactions (Wigglesworth et al., 2022). The uncertain geopolitical environment is expected to reduce investors' risk sentiment, with negative effects on investment in the short term. Furthermore, the new focus on increasing defence spending and energy investments will further raise government debt levels (Oppenheimer, 2022), putting pressure on the already stretched

[6] See Kerr and Kerr (2021), Hunt and Gauthier-Loiselle (2010), Kerr and Lincoln (2010), Bernstein et al. (2018), Moser and San (2019), Doran and Yoon (2018).

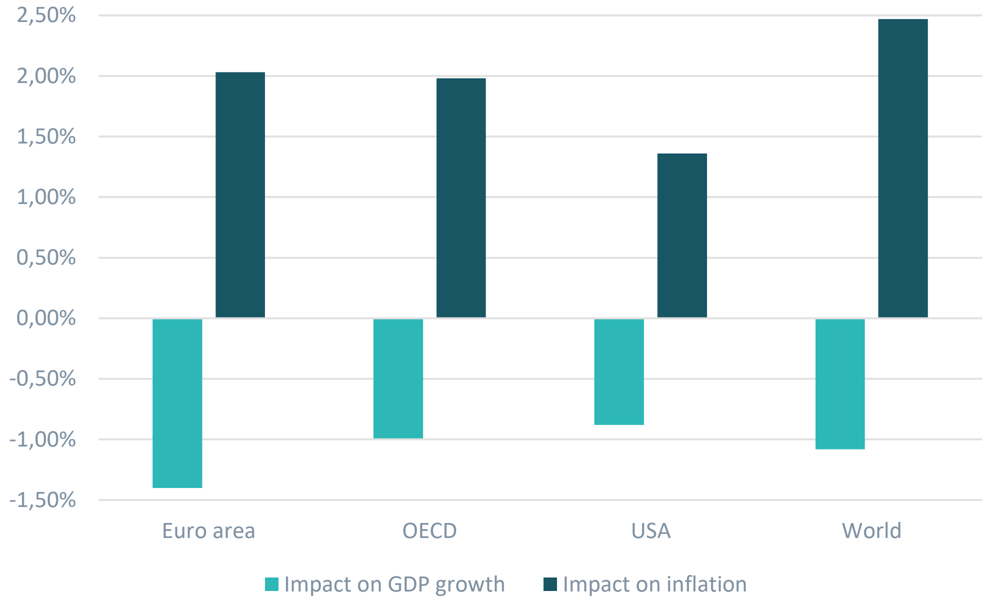
fiscal capacity of several EU countries (Ana Palacio et al., 2022). This may also have implications for the size and allocation of R&D budgets.

Furthermore, many international corporations are discontinuing their activities in Russia. Several well-established brands have decided to immediately leave Russia in response to its attack against Ukraine. Companies cutting ties with Russia operate in a broad range of sectors. Many **oil and gas companies** have started to exit the country (such as, BP, Equinor, Exxon and Shell). Similarly, several companies operating in the **automotive and aviation sector** (e.g., Boeing and Airbus, Daimler Truck, Ford, Mercedes-Benz, VW) have also taken action in response to the attack, by stopping the supply of parts and components, as well as service support to their clients in Russia. Some important companies operating in the **consumer goods sector** have also decided to cease all operations in Russia (including Airbnb, Carlsberg, Disney, H&M and Ikea), while offering support and assistance to Ukrainian refugees (Ivanova and Gibson, 2022). Major corporations like McDonald's, Starbucks and Coca-Cola also left Russia, closing their restaurants and shutting down selling operations (Danielle Wiener-Bronner, 2022).

The uncertainty brought by the war is likely to dampen the expected post-pandemic economic recovery. In the euro area, economic growth is predicted to be around than 1.4 percentage points lower this year than was projected before the conflict. Inflation, which was already high at the start of the year (around 5.1 % in January 2022), is expected to be at least 2 percentage points higher than it would have been had the war not broken out (Figure 8).

A slower economic recovery may imply fewer resources available to finance the R&I required to achieve the green and digital transition. Indeed, R&D investments, particularly the business component, are typically pro-cyclical (Barlevy, 2007; Comin & Gertler, 2006), meaning that R&D moves in tandem with economic growth: it declines during recessions and increases during economic booms.

Figure 8. Estimated economic impact of the Ukraine conflict (over one year)

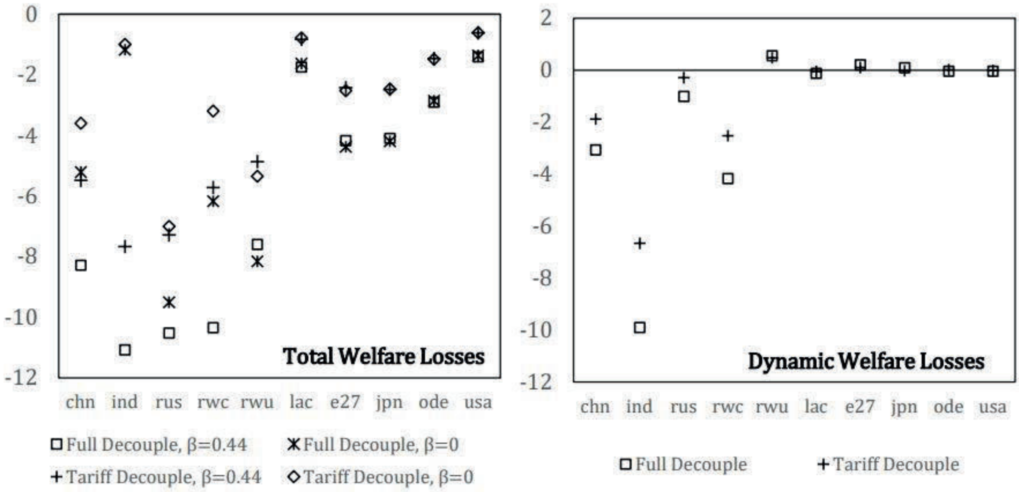


Source: OECD Economic Outlook, Interim Report March 2022. Note: calculations using the NiGEM global macroeconomic model. Percent changes over the 1 year period beginning 24 February 2022.

Furthermore, **the Ukrainian war is expected to impact on global geopolitical relations, calling for a reduction of industrial dependencies in strategic sectors through economic restructuring**. Potential closer alignment between China and Russia will modify profoundly the exchange of energy, raw materials, industrial parts, and goods between the Western world, China, and Russia (Simchi-Levi and Haren, 2022). EU industries, including semiconductors, automotives, and medical equipment, will need to re-organise and re-diversify their supply chains, while fostering local supply chain strategies (see also Section 3.2). In this direction, both the U.S. Chips Act and the European Chips Act are examples of government efforts to reduce dependency on Asia in strategic technological sectors. In relation to energy (see also Section 5.1), with RePowerEU, the Commission recently proposed an outline of a plan to make Europe independent from Russian fossil fuels well before 2030, starting with gas. The Communication on 'Safeguarding food security and reinforcing the resilience of food systems' also illustrates the need to address issues of global food security in light of dependencies, with Russia and Ukraine being responsible for 30% of world wheat exports (European Commission, 2022a).

Such shift in the focus of global trade policy **from mutual economic benefits of open trade policies to geopolitical considerations limiting interdependence will likely have relevant implications for innovation and economic growth**. As an example, Góes and Bekkers (2022) estimate that a hypothetical decoupling of the global trading system into two blocs, a US-centric and a China-centric bloc, would reduce total welfare in 2040 (compared to a baseline without decoupling) by about 5% in the world, around 4% in the West and 10% in the East. Low-income regions would be the most affected ones, as they benefit most from the positive technology spillovers of trade. By cutting ties with richer and innovative markets, less productive countries are likely to shift their supply chains towards lower quality inputs, which, in turn, induce less innovation. The richer western countries would see their innovation path less affected but would still suffer important welfare losses (Figure 9).

Figure 9. Cumulative percentage change in real income after decoupling of the global trading system into US-centric and China-centric blocs, by 2040



Source: Góes and Bekkers (2022). Note: the authors employ a multi-sector multi-region general equilibrium model of Bertrand competition with dynamic sector-specific knowledge diffusion. The estimate points represent the welfare losses (in term of cumulative percentage change in real income) of different countries (chn, China; ind, India; rus, Russia; rwc, Rest of Eastern bloc; rwu, Rest of Western bloc; lac, Latin America; e27, European Union; ode, Other Developed; usa, United States) in case of both full decoupling and only tariff decoupling. β is a parameter capturing the diffusion of ideas.

3.2 The destruction of Ukraine's production and tech capacities

Before the war, Ukraine hosted a vibrant tech ecosystem. Despite being relatively small as compared to other European countries, Ukraine's tech landscape has given home to a significant **pool of tech talent** and entrepreneurs, who gave birth to several **successful start-ups and unicorns** in recent years (such as the Nasdaq-listed software company GitLab, online writing assistant Grammarly and B2B software company People.ai) (Pitchbook, 2022). According to Daxx (Ukraine's third best IT employer), Ukraine counts **more than 4,000 tech companies** and **over 100 R&D centres** that helped the country become an increasingly popular destination for foreign businesses.

The Ukrainian IT developer population has been significantly growing in recent years. Ukraine counts around 16,000 qualified IT specialists and 130,000 general engineering professionals graduating every year (Beetroot, 2021). The growing pool of tech talent is concentrated in Ukraine's **five IT hubs**, notably Kyiv, Dnipro, Kharkiv, Odesa and Lviv. Kyiv alone accounts for about 41% of the Ukrainian tech professionals, followed by Kharkiv and Lviv, with 14% and 10%, respectively (Daxx, 2020). Also**, many venture capital-backed companies abroad have deep connections with the Ukrainian innovation landscape**. Pitchbook lists about 126 start-ups that raised venture capital (VC) funding since the beginning of 2021 with a primary or secondary office in Ukraine (Pitchbook, 2022). Furthermore, around 100 companies included in the Fortune 500 list (ranking the largest United States corporations by total revenue) had remote development teams located in Ukraine in 2020.

The war endangers the immediate future of Ukraine's tech landscape. Several start-ups and Ukrainian employees decided to stay in the country, refusing to evacuate after the beginning of the invasion. Nevertheless, many companies not headquartered in Ukraine, but having offices in the country, have transferred their business operations elsewhere (Pitchbook, 2022). The highly unstable situation makes it difficult to predict the future of companies still present on Ukrainian soil, but the conflict does not leave much optimistic perspective to them.

Furthermore, **the conflict is expected to have repercussions on the European innovation landscape,** through a number of channels. The disruption of the Ukrainian tech industry may **hamper companies externalising tech services and support** to Ukraine in the short-term. **The war is also likely to accelerate the reshoring trend** that had already started as a consequence of the China-U.S. trade war and the pandemic, and will lead to further disruptions of the supply chains. Ukraine is one of EU's top locations for offshoring engineering and IT services, and the disruption of economic activities in Ukraine has direct consequences for corporations in the EU. For instance, the automotive industry, already significantly impacted by supply bottlenecks related to the pandemic, is facing additional difficulties due to the Russia-Ukraine conflict. With key wire harnesses factory in Ukraine being shut down after the Russian attack, companies such as Volkswagen, Audi, Porsche and BMW were impacted in their car production.

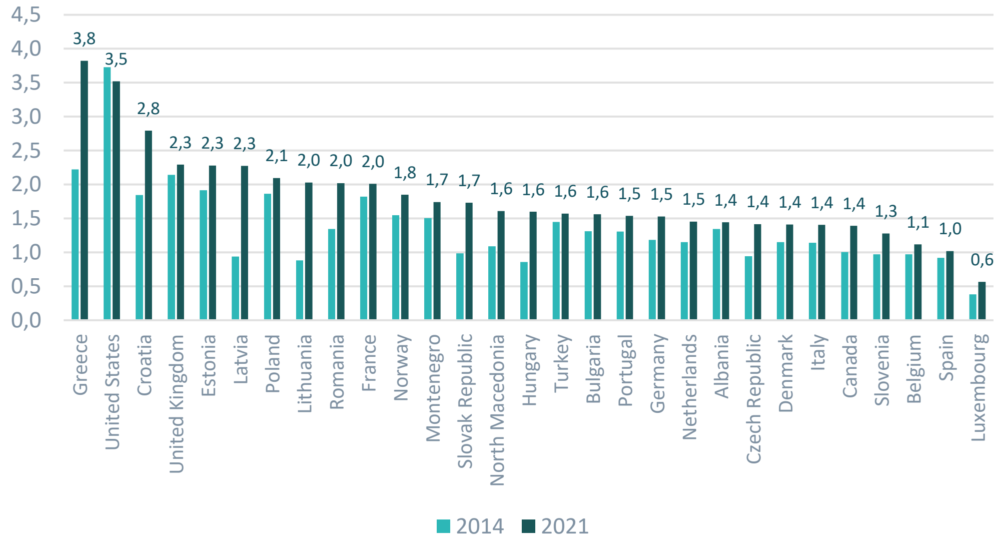
Additionally, **the conflict is expected to worsen the global chips shortage, having severe repercussions on European tech firms and chips manufacturers**. According to Reuters data, approximately 45% to 54% of global semiconductor-grade neon (critical for the lasers used to make chips) is produced by two Ukrainian companies, Ingas and Cryoin, which have been forced to close their businesses after the Russian invasion. In combination with the trade sanctions imposed on Russia, the world's largest producer of palladium (essential to the production of memory and sensor chips), this is expected to heavily impact the semiconductor industry, thereby having significant negative effects on key downstream sectors, such as automobiles and electronics (Reuters, 2022).

4 Impact on defence and security-related R&I

4.1 The need for more defence R&I?

The war naturally brings the defence industry, and related R&D, to the centre stage. In 2020, the five biggest spenders on defence were the United States, China, India, Russia and the United Kingdom, representing together 62% of world military spending. Among these countries, China shows a significant increase of 76% of its military expenditure over 2011-2020 (Lopes da Silva et al., 2021). The NATO guidelines suggest that member countries should spend 2% of their GDP on defence. This guideline is met today by the USA, UK and 8 EU Member States (NATO, 2021): Greece (the highest share amongst the NATO members with 3.8% of GDP), Croatia, Estonia, Latvia, Poland, Lithuania, Romania and France (Figure 10). Since 2014, the share of GDP invested in defence increased for all NATO member countries, except for the USA. The Russian war of aggression against Ukraine may also reinforce this trend. For example, recent announcements in Germany include a special defence fund that can boost German defence spending from around 1.5% of GDP to at least 2% (The Economist, 2022b).

Figure 10. Defence expenditure as a share of GDP (%)



1.

Source: NATO. Note: figures for 2021 are estimates.

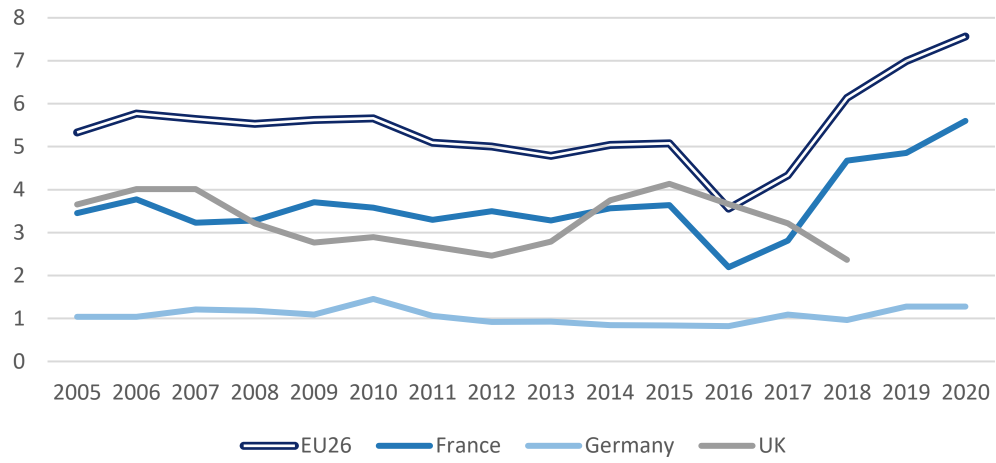
Spending on defence R&D in Europe is low. Compared to the other largest OECD economies, the USA spends a much greater share of GDP on defence R&D (Congressional Research Service, 2020). In the EU, most countries spend little on defence R&D, with the exception of France. The EU budget for defence R&D (without Denmark) amounted to EUR 7.6 billion in 2020[7], which is largely accounted for by France (EUR 5.6 billion) and Germany (EUR 1.3 billion). The total amount of defence R&D in the EU was stable over 2005-2015, then increased significantly after 2016, mainly driven by increased French expenditure (Figure 11). EU expenditure on research and technology[8]

[7] Source: European Defence Agency.

[8] Expenditure for basic research, applied research and technology demonstration for defence purposes. It is a subset of R&D expenditures, which includes any R&D programmes up to the point where expenditure for production of equipment starts to be incurred (source: European Defence Agency).

corresponds to 1.25% of total defence expenditure in 2020, which is below the 2% benchmark of the European Defence Agency.

Figure 11. Defence R&D Expenditure (billion euros)



Source: European Defence Agency. Note: EU26 includes EU countries but not Denmark. Figures include any R&D programmes up to the point where expenditure for production of equipment starts to be incurred.

Compared to traditional civil sectors, the defence sector has specific characteristics, such as cost escalation over time of defence equipment and higher R&D costs (European Commission, 2018b). The cost escalation is a long-term trend for the sector that is driven by intense technological competition at the technology frontier, which is vastly expensive (Hove and Lillekvelland, 2016), while the ratio of R&D costs to recurring costs of defence programmes is considered several times higher than the corresponding ratio for civil programmes (EP, 2016). These factors can limit the launch of new defence programmes, especially making them out of reach for individual EU member states, and impact on the competitiveness and innovation capacity of the EU industry. Furthermore, the defence market does not follow the conventional rules and business models of more traditional markets: demand is almost entirely driven by Member States and their defence budgets and the sector is strictly regulated. Therefore, the industry is not expected to spontaneously launch self-funded defence R&D projects and rather works on demand for a State (European Commission, 2018b).

Hence, R&I in the defence sector hinges on public demand (Moura, 2011; European Commission, 2018b). Several recent policy developments related to defence R&I can be observed. Of particular importance is the diminishing dichotomy between the civilian and the defence sector. At EU level, the European Defence Fund supports defence research with a budget of close to EUR 8 billion over 2021-2027, while Horizon Europe has an exclusive focus on civil applications (see Table 3 for an overview of programmes and instruments related to defence and security R&I). In its 2022 Communication on the roadmap on critical technologies for security and defence (European Commission, 2022b), the Commission highlights that these technologies increasingly originate in the civilian domain and use critical components of a **dual-use nature**. Against this backdrop, it announces the preparation of an approach for encouraging dual-use R&I across EU programmes and instruments. In a recent declaration[9], drawing lessons from the ongoing military aggression against Ukraine, **EU leaders** also stressed the importance to invest more and better in defence capabilities and innovative technologies. It was agreed to substantially increase defence expenditures, foster synergies between civilian, defence and space research and innovation, and invest in critical and emerging technologies and innovation for security and defence.

Table 3. EU programmes and instruments supporting R&I in critical technologies relevant to security and defence

Programme/instrument	***Link to defence and security***
European Defence Fund (EDF)	EUR 8 bn to defence R&I
Horizon Europe	- EUR 1.6 bn cluster 'Civil security for society' to address challenges to border control, counter cybercrime, improve disaster-resilience and security of critical infrastructure - Critical technologies supported also under other clusters (e.g. cluster 'Digital, Industry and Space') - Complementary activities under Excellent Science, European Innovation Council, European Institute of Innovation and Technology and European partnerships
Digital Europe Programme (DEP)	Deployment activities related to cybersecurity, AI and supercomputing
Cybersecurity Industrial, Technology and Research Competence Centre and Network of Coordination Centres	These will adopt a strategic agenda on cyber investments feeding into Horizon Europe and DEP. Synergies between civilian and defence technologies and dual use applications may be explored through links to EDF in line with applicable rules.
European structural and investment funds	The funds can be used in support of the European Defence Technological and Industrial Base
Other	Other relevant EU programmes, funds and instruments include the Space Programme, CEF, InvestEU Programme, the Recovery and Resilience Facility (RRF), LIFE Programme, public-private partnerships, blending facilities

Source: authors' elaboration based on the Communication on the Roadmap on critical technologies for security and defence (European Commission, 2022b).

4.2 A digital war

Modern warfare has been progressively assuming a hybrid form, aiming at inflicting large-scale damage not only through direct engagement on the battleground. Non-traditional military means, encompassing economic, diplomatic, information and political warfare, have gained importance. In this regard, **technological progress has played an important role in transforming military strategies.** Unconventional

[9] https://www.consilium.europa.eu/media/54773/20220311-versailles-declaration-en.pdf

warfare requires the deployment of advanced technical tools and digital systems targeting critical components of an opponent's economy and society, from physical infrastructures to core societal values (Danyk et al., 2017).

Digital technologies are widely used in modern warfare. For example, cyber-attacks can target a country's key digital systems, resulting in severe **data breaches and security emergencies**. On the other hand, digital tools can be used to **manipulate information flows**, as well as to increase the number of fake news on the web and propaganda activities (Masse, 2021). In addition, the deployment of high-tech technologies against priority targets potentially allows for hitting strategic infrastructures with maximum speed and precision, but avoiding physical presence.

Hybrid warfare is not a new experience for both Russia and Ukraine. Already in 2014, during the tensions linked to the Crimea annexation, military operations were not limited to standard military incursions. Digital technologies were used to take control over the society as a whole, through digital propaganda and misinformation. Cyber-attacks carried out by Russia in the context of the 2014 Ukraine-Russia tensions mostly aimed at creating disaffection and mistrust towards Ukrainian primary military and political authorities, thereby manipulating Ukrainian people's perception of the conflict (Danyk et al., 2017).

Similarly, the current Ukraine-Russia crisis is also characterised by a significant cyber component. Since the beginning of 2022, Ukraine has been subject to a number of cyber-attacks perpetuated by the Russian authorities (Gartner, 2022). In January 2022, Microsoft reported the identification of malicious software targeting the government of Ukraine and non-profit organisations, as well as IT entities (Microsoft Security Blog, 2022). In early February 2022, Microsoft also reported that the Actinium group (a hacker group considered to be linked with Russian security services) started targeting Ukrainian military offices and government networks to gather intelligence (Microsoft Security Blog, 2022b). Furthermore, as noted by Wolff (2021), Russian cyber capabilities are becoming more sophisticated, and are no longer limited to traditional phishing techniques or denial-of-service attacks. As the complexity of cyber techniques increases, so does the probability of them being used to conduct cyber espionage activities, targeting key sectors related to energy, defense and high-tech industries (Crowdstrike, 2021).

With the increase in the number of cyber-attacks and disinformation campaigns, **security threats are becoming more diverse** and no longer have an exclusive military nature. In 2020, the European Commission presented the new EU Cybersecurity Strategy, aiming at strengthening the leading role of the EU as setter of international norms and standards in the cyberspace, in full compliance with EU rule of law, fundamental freedoms and democratic values. Furthermore, in its communication of March 2022 on the new European growth model, the Commission stresses the importance of **strengthening EU cyber resilience**, by reducing strategic dependencies and increasing investments in areas related to cyber security (European Commission, 2022c). Regarding disinformation, tactics and their effects on society have been studied by around 40 Horizon 2020 research projects for an amount of about EUR 76.5 million.

Further and more targeted research to improve capabilities to fight disinformation and foreign interference will be funded under Horizon Europe in 2022 and 2023 (Cluster 2 "Culture, creativity and inclusive society").

Digitalisation also helps to channel support to countries in distress. In this regard, **technology is being used in various ways to support Ukraine** in the midst of the Russian invasion (World Economic Forum, 2022). Several companies around the world have initiated digital fundraising campaigns to help the Ukrainian population after the Russian military attack, for example by the company Revolut through its fintech (Sifted, 2022). Furthermore, SpaceX billionaire Elon Musk has announced the activation of company's Starlink satellite broadband service to keep Ukraine online, and more terminals have been sent to the country (World Economic Forum, 2022). **Additionally, fintech (financial technology) also became one of the world's main advantages against Russia** (Gersem, 2022). The set of sanctions issued against Russia in the aftermath of the invasion included a rapid shutdown of Russian banking around the world, and the disconnection of individual Russian banks from the SWIFT electronic payment system (Kirschenbaum and Véron, 2022).

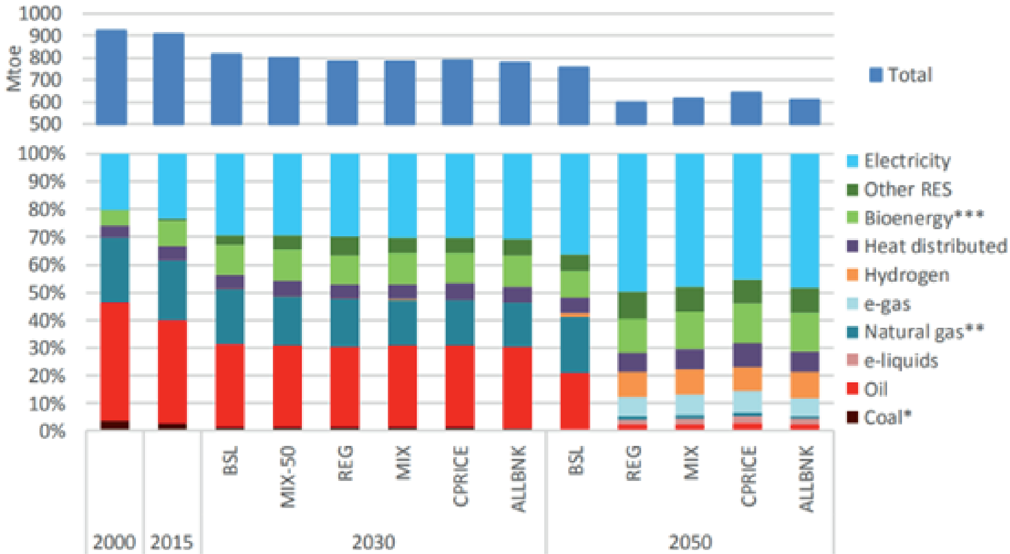
5 Societal impact

5.1 Is the implementation of the European Green Deal at risk?

The pace of implementation of the European **Green Deal could be impacted by the geopolitical context.** Following the adoption of more ambitious greenhouse gas emission target for 2030, the European Council recalled that EU member states were free "to decide on their energy mix and to choose the most appropriate technologies to achieve collectively the 2030 climate target, including transitional technologies such as gas".[10] Estimates of the European Commission (2020b) (Figure 12) envisage that most of the changes in oil and gas consumption would happen between 2030 and 2050. Natural gas would end up contributing just a tenth of EU energy in 2050 if the European Green Deal is implemented (Leonard et al., 2021), but, **between 2030 and 2050, it will be a major transitional source.**

[10] https://www.consilium.europa.eu/media/47296/1011-12-20-euco-conclusions-en.pdf

Figure 12. EU energy mix evolution – target: -55% lower emissions in 2030 compared to 1990 and climate neutrality in 2050



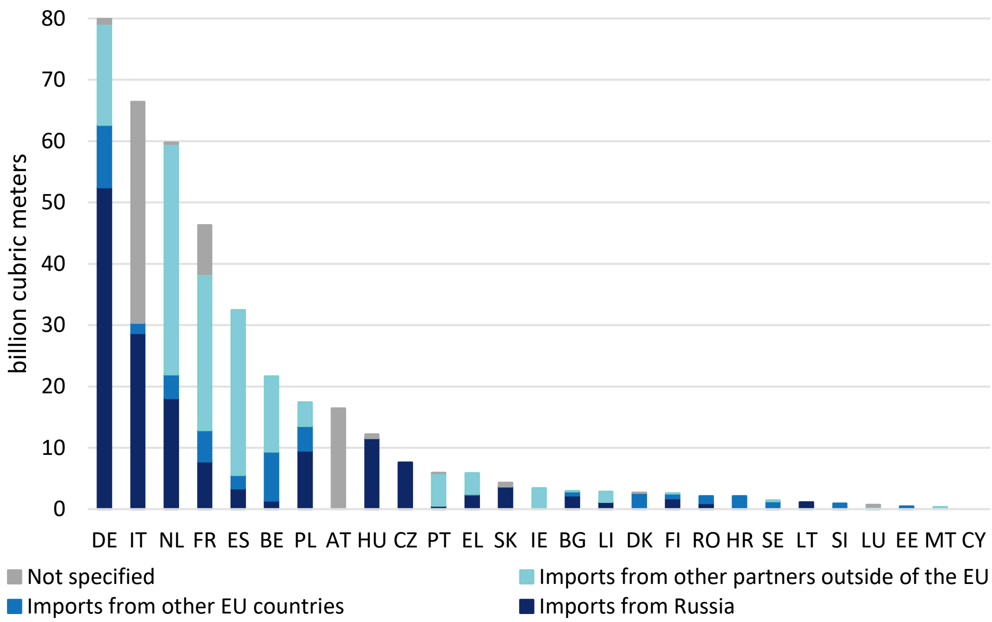
Source: European Commission (2020b)
Note: BSL, MIX-50, REG, MIX, CPRICE, ALLBNK are scenarios with different levels of ambition for energy efficiency and renewables as outcomes. REG includes the modelling of relevant policies, MIX includes the interaction of such policies with carbon pricing and CPRICE the carbon pricing in combination with different intensification of transport policies. ALLBNK shares similar policy instruments as in MIX, but more intensified notably in terms of transport fuel mandates in order to meet the increased GHG ambition due to inclusion of extra-EU aviation and navigation in the scope of GHG emissions.
*Note: * includes peat, oil shale, ** includes manufactured gases, *** solid biomass, liquid biofuels, biogas, waste.*

Overall, the Russian invasion of Ukraine has revealed the vulnerabilities of the EU energy sector. The EU imports 92% of the natural gas it consumes. The total 155 billion cubic meters imported from Russia accounted for around 45% of the EU's gas imports in 2021 and almost 40% of its total gas consumption (IEA, 2022). Some countries rely almost fully on Russia for their natural gas imports, such as Hungary, Slovakia and Latvia. Also Germany and Italy imported most of their natural gas from Russia. France and the Netherlands' supplies rely less on Russia, low dependency can be seen in Portugal and Spain and almost no dependency on Russian gas exists in Ireland and Malta (Figure 13). Cutting the imports from Russia would definitely have a negative impact on the European economy, though the effects would differ across Member States. **The need to reduce EU dependency on Russian gas risks to force European countries to resort to fossil energy sources to meet EU's energy needs, even if other options are possible.**[11] This would mean a significant setback

[11] For example, the IEA has proposed a 10-point plan for the EU to reduce reliance on Russian gas: https://www.iea.org/reports/a-10-point-plan-to-reduce-the-european-unions-reliance-on-russian-natural-gas.

on EU's climate goals, putting into question the successful implementation of the EU decarbonisation process.

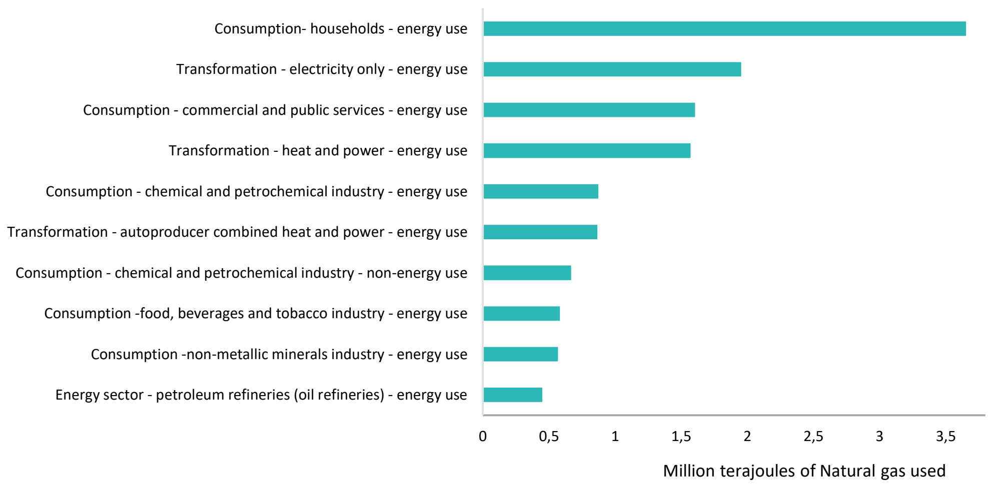
Figure 13. Total natural gas imports, 2020



Source: Eurostat.

R&I investments and efforts should be strengthened to accelerate the development and deployment of energy efficient and clean energy technologies that would secure both EU independence and competitiveness. Some sectors in particular rely specifically on natural gas, such as energy consumption in buildings and infrastructures (Figure 14). In those sectors and beyond, it is critical to foster R&I to ensure more independence. The EU renovation wave that was launched in 2020 is a step towards this path, as well as the Recovery and Resilience Facility under which many investments were directed towards energy efficiency in buildings and climate-related R&D. **The EU Framework Programmes (FP) for R&I**, with a budget that has increased substantially since the FP1 over 1984-1987 (3.2 billion euros) to the current 2021-2027 Horizon Europe (95.5 billion euros), have included more directionality serving the objectives of the European Green Deal. A 35% target for climate action was included in Horizon 2020 and Horizon Europe. **Horizon Europe will also implement EU-wide R&I missions** (European Commission, 2017; 2018) with ambitious goals to tackle major societal challenges for Europe, such as climate change, healthy oceans, climate-neutral and smart cities, and soil health and food. 7.5% of the 2021-2027 Multiannual Financial Framework should be dedicated to biodiversity objectives by 2024. In addition, the "Do No Harm Principle" is enshrined in the European Green Deal and relevant legislation. To reduce its dependency on Russia, the EU will also have to implement a thorough diversification of its energy import portfolio and leverage as much as possible its in-house energy capacities.

Figure 14. Top 10 sectors in the EU for transformation and consumption of natural gas, 2020

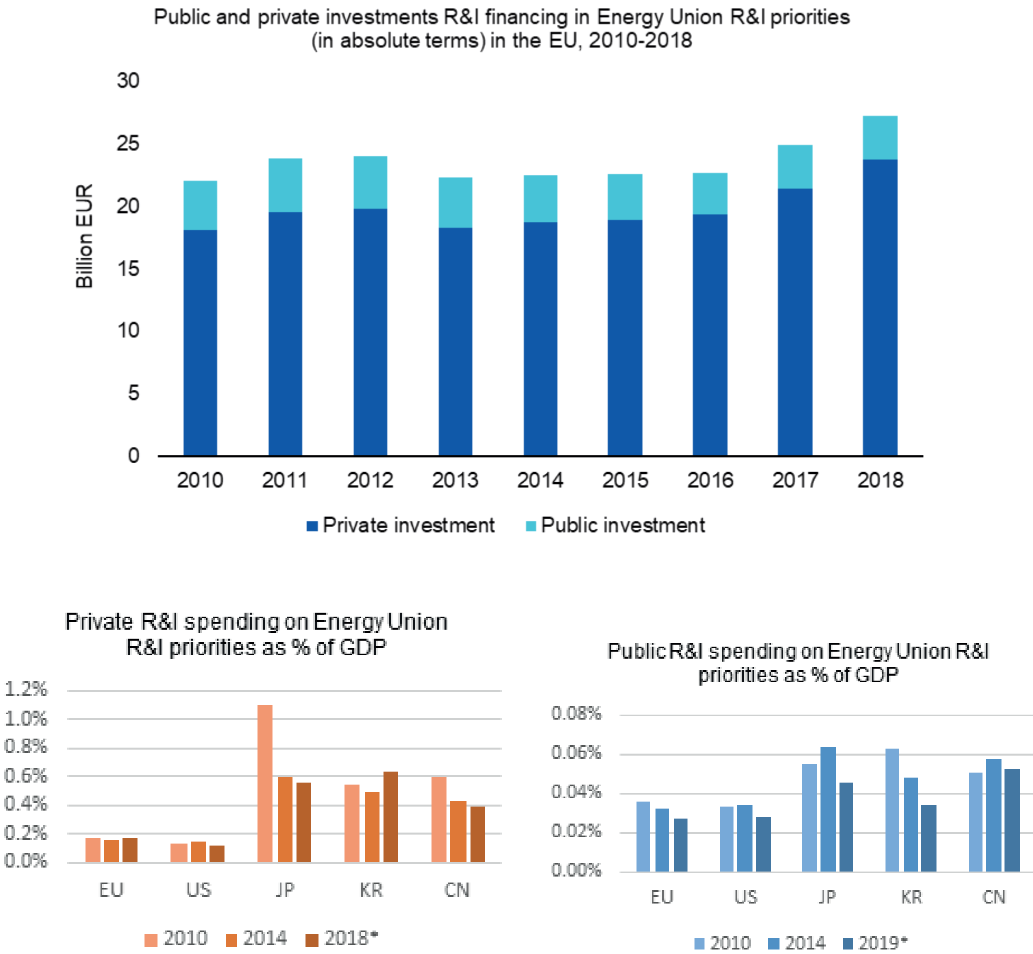


Source: Eurostat.

EU public and private investment in R&D in the field of climate mitigation activities has grown, but at a slow pace over the last five years (EIB, 2021). Overall, the United States has experienced a higher increase and remains the world leader in climate-related R&D. Due to a very high increase, China overtook the EU in 2018 and has a significant lead in 2019. Besides, public and private investments in R&I prioritised by the Energy Union[12] have increased in absolute terms between 2014 and 2018, but it does not keep pace with increases in GDP or R&I spending in other sectors (Figure 15). The EU investment rate (0.027% of GDP) in renewables, smart system, efficient systems, sustainable transport, CCUS[13] and nuclear safety is currently the lowest of all major global economies, just below the USA, though levels seem to be decreasing or stable for all. Moreover, the EU private sector experienced a 7% reduction in overall energy R&I spending during 2020, possibly due to the Covid-19 pandemic. Only spending on renewable energy R&I was more resilient and continued to grow (European Commission, 2021b).

[12] Renewables, smart system, efficient systems, sustainable transport, CCUS and nuclear safety (European Commission, 2015).
[13] Carbon capture, utilisation and storage.

Figure 15. Public and private investments R&I financing in Energy Union R&I priorities (in absolute terms and in % of GDP) in the EU and in major economies.

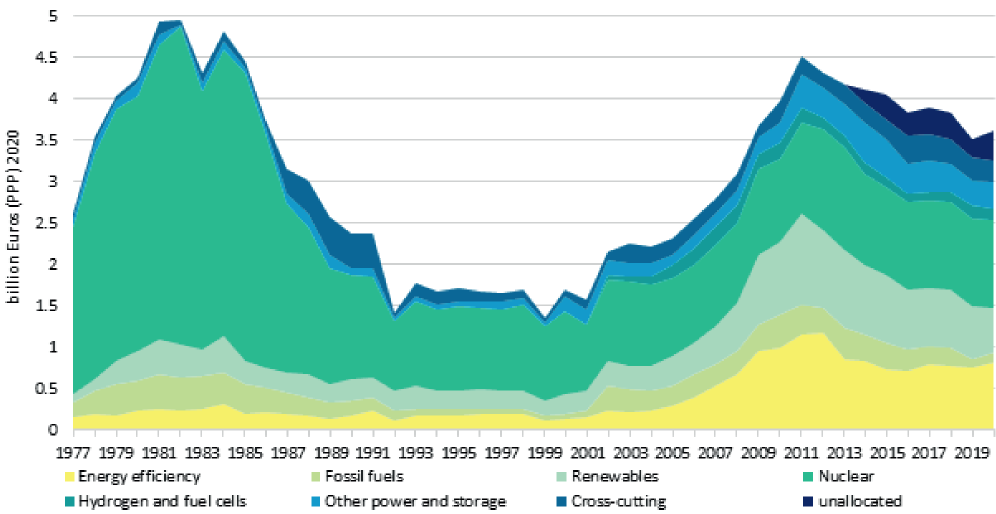


Source: Joint Research Centre, 2021 based on International Energy Agency (2021) and their own work.
Note: public R&I data for China and Italy (in EU total) refer to 2018; private R&I data for 2018 are provisional.

In the EU, public R&D investments in energy have switched from predominantly nuclear to a more diversified mix, including a high share dedicated to renewables and energy efficiency. Over the past forty years, EU public investment in energy R&D has become progressively more diverse (Figure 16). Nuclear power, which accounted for 78% of the total in Europe in 1977, declined every year to 29% in 2020. R&D budgets for fossil fuels, which were at their highest in the 1980s, have declined since 2013 and budgets for both energy efficiency and renewables expanded significantly during the 2000s. At the same time, more and more public R&D spending went to low-carbon technologies (IEA, 2021). **As a result, in 2019, around 80% of**

worldwide public R&D spending on energy was dedicated to low-carbon technologies – energy efficiency, CCUS, renewables, nuclear, hydrogen, energy storage and cross-cutting issues such as smart grids. However, it is worth noting that budgets for hydrogen and fuel cells maintained their share at 3-4% for the period 2000-2020.

Figure 16. Public R&D investments in energy in the EU, 1977-2020



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on International Energy Agency. Note: Only 20 of the 27 Member States were taken into account: AT, BE, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LI, LU, PL, PT, SK, ES, SE. It does not include the European Union R&D FP budget.

Will the invasion of Ukraine by Russia act as a wake-up call for the EU to invest more in R&I to implement the European Green Deal, its independence and competitiveness? The past Russia-EU gas disputes have reinforced the transition to renewable energy. Such patterns were seen after the Russia-Ukraine gas crisis in 2006-2009, during which Russian gas supplies to the Ukraine and the EU were stopped twice, affecting most EU countries, notably Poland, Slovakia, Hungary, and above all Bulgaria and Romania. In 2014, another gas conflict arose between Russia and Ukraine, intermingled with the Ukrainian civil war and the annexation of Crimea by Russia that year with new cuts in gas supply, posing a threat to supply to the EU (Flouri et al., 2015; Rodríguez-Fernández et al., 2020). Following these crises, some EU member states strongly pursued the development of renewable energy (Su et al., 2021), while others diversified their energy supplies in order to reduce geopolitical risk.

5.2 Consequences of the war for society

The massive migration flows towards the EU following the Russian invasion of Ukraine call for joint and coordinated action. European countries will face a number of challenges related to hosting Ukrainian people and providing adequate financial and psychological support.[14] The large scale of refugee flows call for the mobilisation of significant resources to guarantee accommodation, access to healthcare, transport, integration and education. In this regard, an uneven distribution of refugees across EU Member States risks to be too burdensome for some countries, fuelling the already existing **social disparities between and within countries**, as well as the so-called "geography of discontent" (McCann, 2019). This calls for a coordinated approach.

R&I policy has a role to play in addressing the societal impacts of the war. Security will be one of the main priorities for EU countries welcoming Ukrainian refugees. Digital tools and infrastructures could help to ease the **tracking of the arrivals**, as well as **information sharing** across EU countries hit by the migratory pressure. Digital applications have also the potential to support Ukrainians' integration in the host countries, by providing **easy access to language courses** and **other training programmes.**

Furthermore, the war-related supply chain disruptions will further foster inflationary pressures, hitting hard European citizens' pockets. Russia and Ukraine are important food producers, accounting together for 60% of global production of sunflower oil and 29% of global wheat export. Russian gas accounts for about 40% of the EU's natural gas imports (Josephs, 2022). High levels of inflation (well above the 2% ECB target) affect prices and wages disproportionately across the population, influencing the income distribution and distorting purchasing power. Variations in relative prices also lead to more uncertainty, making it harder for firms to make decisions about the future, such as investment decisions.

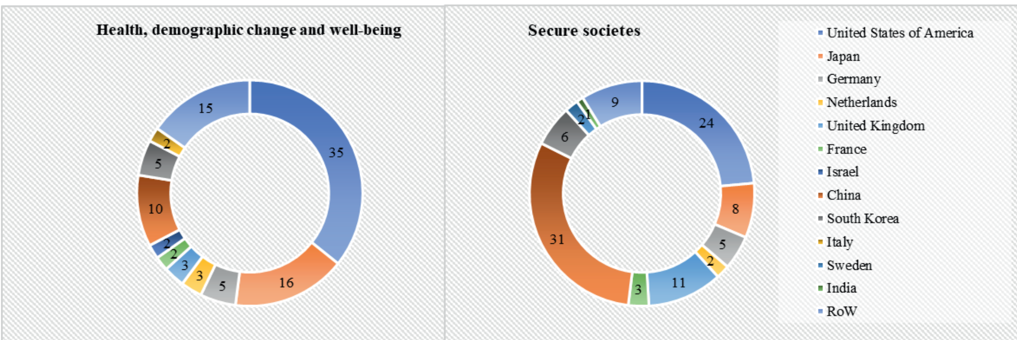
The shift of resources and international attention towards the defence and security dimensions may also delay the achievement of other societal objectives. In time of war, individuals, and societies tend to prioritise survival and self-preservation over environmental protection and social security nets (Levy & Sidel 2008). This may change the directionality of investments and delay the development and uptake of new breakthrough technologies capable of raising living standards and freeing from misery the many individuals still living in poverty, while at the same time staying within the planetary boundaries and reducing human environmental impact on the planet.

In the long-run, **geopolitical tensions,** which arise due to the invasion of Ukraine, **may affect international cooperation, a key aspect in the transfer of innovative**

[14] See Stukalo and Simakhova (2018) for the social and economic effects of the earlier invasion in Eastern Ukraine.

technologies and products to less developed territories and communities. Technological innovation mainly happens in high-income countries. About 85% of global patent applications related to secure societies and health, demographic changes and well-being come from ten countries only (Figure 17). In this context, technology transfer and diffusion are critical to achieve sustainability, secure our societies, cope with global health crisis and ensure well-being for a growing world population. R&D international cooperation agreements, and international cooperation more generally, are major drivers to diffuse innovation across borders, facilitate knowledge sharing and technology uptake (Rogers et al., 2001; Corsi et al., 2020). Finally, the Paris Agreement establishes that **countries must engage in a cooperation involving the international transfer of solutions and outcomes to achieve sustainable goals** (UNFCC, 2015). Will such engagement be maintained in a polarised world?

Figure 17. World share of Total PCT patent applications related to health, demographic change, well-being and secure societies, 2018



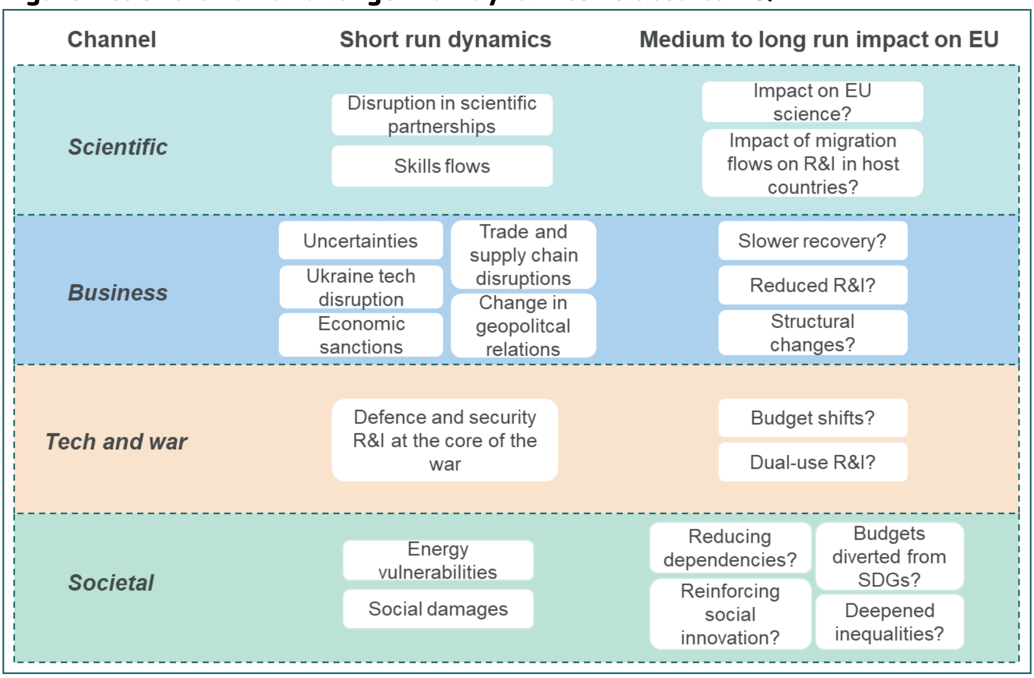
Source: Science-Metrix based on Patstat. Note: fractional count.

Finally, migratory flows may become a driver for innovation. In addition to the direct impact related to skills flows (see section 2.2), the social changes produced by migration flows could lead to the development of new and more innovative solutions to meet the changed local needs, triggering new social learning processes (Manzini, 2016). In this regard, **social innovation** has the potential to offer novel approaches to contemporary crises that differ from traditional technology-based solutions and would then be complementary to these in achieving Sustainable Development Goals (Haskell and al., 2021). According to OECD (2015), social innovation refers to the design and implementation of new solutions that imply conceptual, process, product, or organisational change, which ultimately aim to improve the welfare and wellbeing of individuals and communities. Moreover, stakeholder engagement, citizen participation, citizen empowerment, cross-sectoral collaboration are key aspects of social innovation (Chatfield and Reddick, 2016). This human dimension can become even more fundamental in times of crisis for transforming our society and facilitate the design, adoption and diffusion of socially-responsible innovative solutions.

6 Conclusions: the role of R&I policy

War can have several implications for R&I. In this paper, we highlighted dynamics that take place in the course of the Russia's invasion of Ukraine as well as expected dynamics in the longer-run (see Figure 18). In the short-run, expected disruptions call for **protection and mitigation** measures. Although Russia is not the most important scientific player on the global stage, ending **scientific collaborations** with Russian scientists may affect EU scientific activities, particularly in fields where Russia is specialised, such as energy and natural sciences. At the same time, millions of refugees are flowing out of Ukraine, which raises the importance of immigration as one aspect that also relates to R&I policy, as **immigrants** are strongly over-represented among inventors and entrepreneurs. The military aggression is also expected to significantly impact the European landscape from the **economic perspective**. Uncertainties can discourage investments, the disruption of the Ukrainian tech industry will exacerbate tech shortages and the closure of key Ukrainian companies, together with trade sanctions imposed on Russia, may significantly affect technology supply chains, including through the semiconductor industry, impacting key sectors such as automotive and electronics. As R&I spending is typically pro-cyclical, the current crisis can lead to its decline. In the longer-run, given other competing demands on public spending and high levels of public indebtedness in many EU countries, the case for public R&I investments needs to continue to be made.

Figure 18. Short-run and longer-run dynamics related to R&I



Source: Authors' elaboration.

In the medium to longer term, as for the COVID-19 crisis, the military aggression against Ukraine shows that Europe needs **preparedness** for the challenges we know as well as being ready for new ones. The rising environmental, geopolitical, economic and social instability in the world increases the likelihood of extreme events with disruptive effects, and with potentially unknown specific shape. Such extreme events emphasise the importance of foresight to increase preparedness and make EU R&I policy more agile to effectively respond in a crisis situation. One aspect of the discussion on preparedness also relates to **defence and security R&I**. Even more than in traditional sectors, public support almost exclusively drives R&I in the defence sector. Recent policy developments (European Commission, 2022b) encourage the dual-use of R&I, overcoming the separation between EU civilian and defence R&I. This is also supported by the fact that, with increased number of cyber-attacks and disinformation campaigns, security threats have become more diverse and not of military nature only.

In close relation to the need for preparedness, the Russian invasion of Ukraine has also emphasised EU vulnerabilities, calling for reinforcing **resilience** and addressing issues of EU dependencies, including strengthening EU **technological sovereignty**. In particular, the Russian invasion in Ukraine has revealed the vulnerabilities of the EU energy sector. The new emphasis on the need to reduce EU dependency on Russian gas implies that R&I investments and efforts must be strengthened to accelerate the development and deployment of energy efficient and clean energy technologies, **securing the implementation of the European Green Deal** as well as EU independence and competitiveness in achieving it. In this context, R&I policy can play a major role in shaping the direction of innovations and choices concerning the portfolio of energy technologies. More generally, the conflict magnified the idea that **innovation policy of the future will have to be developed in a complex triangle of transformation policies, competitiveness policies and technology sovereignty considerations**. However, in doing so, the EU should avoid sacrificing international welfare gains through free trade and division of labour for short-sighted technology sovereignty policies driven by domestic interest groups (Edler et al, 2021).

Finally, **R&I can also act as a lever for peace**. Global research community has condemned the Russian invasion of Ukraine. This includes thousands of scientists in Russia, who were shocked by the actions of their government (Gaind and Else, 2022). Furthermore, research and innovation are at the basis of sustainable socioeconomic development and therefore peaceful societies. Science diplomacy is bringing together researchers across the world to work together at solving problems that cross borders and span continents, such as energy, water security or climate change, which can have repercussions in terms of conflict.[15] Overall, one should not neglect the potential of R&I as a catalyst for peace.

[15] "In some parts of the world, climate change is changing the sources of conflict—the control over a dam or a lake can be more strategic than an oil refinery. Climate change is even one of the root causes of a new migration phenomenon. Climate refugees will become a new challenge—if we do not act swiftly." (State of the Union 2015, https://ec.europa.eu/info/sites/default/files/state_of_the_union_2015_en.pdf).

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This paper aims to identify and investigate the impact of the invasion of Ukraine by Russia in early 2022 on research and innovation (R&I) in Europe. The war itself, together with associated sanctions, migration flows, unstable economic environment, supply chain disruptions and energy dependencies, affects EU R&I through several channels, ranging from scientific collaboration and availability of researcher to economic implications for businesses, progress in green transition, social impact, and increased demand for defence and security. The conflict has both short- and longer-run implications for policy. In the short run, expected disruptions call for protection and mitigation measures. In the medium to longer term, as for the COVID-19 crisis, the conflict underlines that Europe needs preparedness as well as reinforced resilience and a reconsideration of EU dependencies. R&I can also be seen as a lever for peace, being at the basis of sustainable socioeconomic development and therefore peaceful societies.

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