Chasing shadows: technology and socioeconomic barriers versus climate targets for iron and steel industry

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Abstract: The possibilities of reaching the steel industry's sectoral targets consistent with global climate agenda have been studied. A window of opportunities still exists but shrinks. Modernisation shall include global deployment of Best Available Technologies, increased secondary steel production and rapid commercialisation of innovative technologies including Carbon Capture and Storage. International policies shall ensure availability of funding and technology transfer. Short term strategies shall be employed as soon as possible to bridge long term projections and current state of steel industry worldwide.

Key words: Iron and steel industry, climate change, mitigation, modernisation

1. Introduction

Iron and steel sector is the largest emitter of greenhouse gases (GHG) responsible for 31% of industrial and 6.7% of anthropogenic emissions worldwide [1]. Therefore, reduction of its carbon footprint is indispensable part of any climate change mitigation scenario.

Currently, after energy efficiency of steelmaking was enhanced by 60% since 1960 [2], the sector has reached a level when further deployment of best available technologies (BAT) has limited carbon abatement potential. At the advanced factories BAT penetration has reached the saturation level where only expensive technologies with long payback period are not deployed yet, whereas the "low hanging fruits" are already picked up. Therefore business as usual development scenario cannot decouple GHG emissions from growth. Some breakthrough technologies capable to cut GHG emissions beyond the BAT potential are being developed; however, in short-term perspective their effect on global emission can hardly be significant.

Steel remain the basis of modern civilization and will inevitably remain the backbone of industrialization in the developing countries in a long term. So, even if accomplished using the cutting-edge level, growth of wealth in the developing world remain coupled with growth of GHG emissions.

In many industrially developed countries, the steel sector is often strategically covered by protectionist measures aimed to avoid excessive carbon cost. E.g. in the European Union steel sector participates in the EU Emission Trade Scheme (EU ETS) designed to cut GHG emissions, however is included to the list of industries vulnerable to leakage and receives 100% of emissions allowances for free and this approach will persist beyond 2021 [3]. This do not incentivises sector's transition towards technologies with low carbon footprint.

In Ukraine in 2018 a CO_2 emissions tax is set at the level of just 0.41 UAH (ca US$ 0.016) per t [4] which is far not heavy load for the industry to bear. According to the EU-Ukraine Association Agreement, Ukraine is committed to transpose EU legislation in the climate sphere and to implement GHG emissions allowance trade scheme within 2 years from the Agreement's entry into force (i.e. by September 2019). Although steelmakers' association Ukrmetalurgprom recently informed about cooperation with the Ministry of Ecology on estimation of the feasibility margin for the GHG emissions allowances for mining and metallurgy industry [5], the details of this study have not been made public. The approaches to allowances distribution are not disclosed as well.

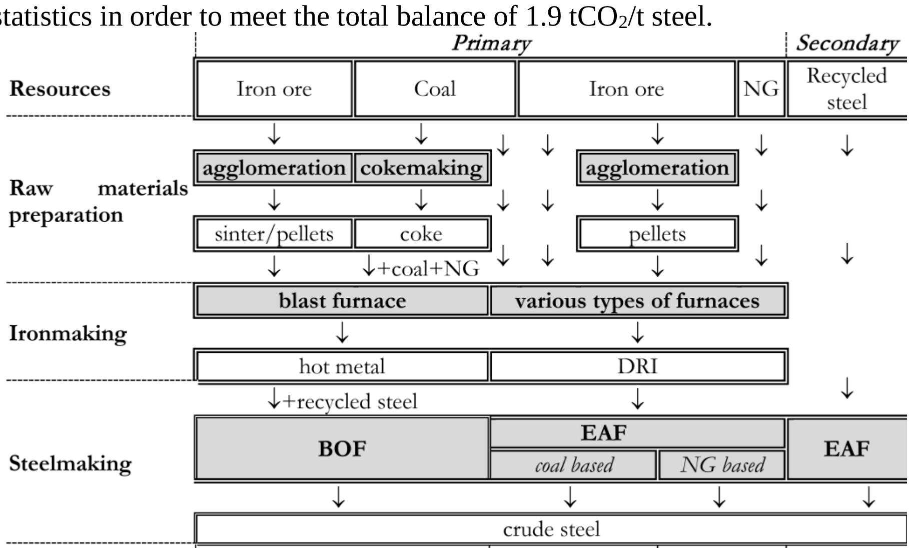
Definition of future pathways for iron and steel industry modernisation is very important in terms of compliance with the global climate agenda. However, inherent features of iron and steel industry such as very high investment cost, large factories size, overcapacity etc leave very little space for hope that this modernisation will be indeed performed towards meeting climate targets.

2. MethodologyEstimation of sectoral climate target

To date the most comprehensive scenario with clearly defined sectoral tasks consistent with global climate target remains 2 Degrees Scenario (2DS) by the International Energy Agency (IEA) which describes energy system consistent with limiting global warming to 2°C with 80% probability by the end of this century [1]. 2DS uses 2011 as a benchmark and implies decoupling of the emissions from growth, envisaging reduction of CO_2 emissions from 2991 Mt to 2044 Mt coupled with growth of crude steel production from 1518 Mt to 2295 Mt in a low demand scenario and to 2568 in a high demand scenario in 2050. In the business as usual scenario (6DS) emissions would grow up to 3667 Mt CO_2 in 2050. In this work we optimistically use 2DS low demand scenario for estimation of sectoral climate target

2.2. Crude steel production intensity

Variety of steel production routes is summarized in Fig.1. For the simplicity some technologies with small market share are omitted and some materials, electricity and by-products are not indicated. World Steel Association (WSA) several years in a row reports average intensity of 1.9 tCO_2/t steel [6]. For each country, of course, carbon intensity (both average and for specific routes) is different and depends upon the particularities of infrastructure and BAT penetration. As an example Fig. 2 demonstrates historic data on carbon intensity of steel production for Ukraine and for the EU28. Sources of such an impressive difference in the GHG emissions' intensity are much higher energy intensity of steel production in Ukraine (mostly owing to use of open hearth furnaces and ingot casting) as well as specific infrastructural differences: (i) the EU produces ca 40% of steel through recycling of scrap in electric arc furnaces, while in Ukraine ca 95 % of steel is produced via more carbon intensive primary route; (ii) Ukraine completely relies on its own iron ore materials, whereas EU uses certain amount of imported pellets, hence some upstream emissions for the EU are not taken into account. In early 2000 carbon intensity in Ukraine declined thanks to reduced shares of OHF and ingot casting in steel production but since 2012 it grew up again owing to switch from natural gas to pulverised coal for injection into blast furnace tuyers. In this study average data for each route are derived from the WSA statistics in order to meet the total balance of 1.9 tCO_2/t steel.



	BOF	EAF coal based	EAF NG based	EAF (secondary)
CO_2 intensity, tCO_2/t steel: range (2016)	1.8-2.6 (2.29)	3.3-3.7 (3.5)	1.3-1.6 (1.4)	0.2-0.9 (0.6)
Market share,%	74.7	0.58	2.77	21.95
CO_2 emissions share,%	89.37	1.08	2.04	7.51

Fig.1 Steel production routes (BOF – basic oxygen furnace, EAF – electric arc furnace, NG - Natural gas, DRI – direct reduced iron)

Obviously, with respect to impact of each route and specific weight of particular technologies, substantial cutting of CO_2 emission can be achieved via the following options:

(i) increased share of secondary route;
(ii) enhanced energy efficiency by deployment of BAT;
(iii) deployment of innovative technologies (e.g. novel ironmaking methods where cokemaking and ore agglomeration can be phased out);

(iv) deployment of breakthrough technologies with ultra low carbon intensity
(v) carbon capture & storage (CCS).

2.3. Non-innovative scenarios

2.3.1. Business as usual

Business as usual (BAU) scenario used in this study was devised with constant EAF share in steelmaking, current BAT penetration level and no innovative technologies deployment. However, BAU includes gradual (S-curve) decarbonisation of electricity by 2050 and phasing out of coal-based DRI production.

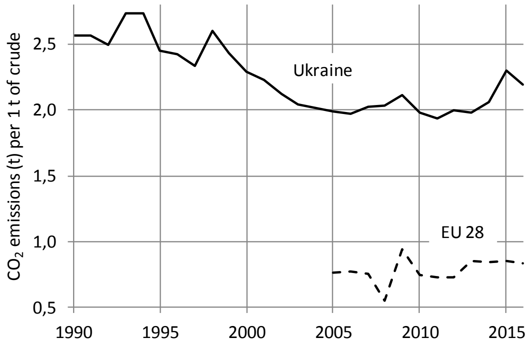


Fig. 2 CO_2 emissions intensity of steel production in the EU28 and Ukraine (author's elaboration on [1, 7, 8])

2.3.2. CO_2 abatement by increased secondary steel production

As seen from Fig.1, increased share of steel produced from scrap can substantially reduce sector's CO_2 emissions; however, current and future steel demand cannot be met only using the scrap available. 2DS aims at 37% of steel produced in EAF from scrap in 2025 [1]. Another forecast [9] assumes that global demand for steel can be met by producing 40% of steel from scrap in EAF by 2035. Pauliuk et al [10] argue that up to 50% of steel demand can be met by scrap available in 2050. Statistic data (Fig.2) show that after declining for 15 years in a row the EAF share finally increased by 2.7% in 2016 year on year, mostly owing to icrease of this share in China from 5.2 to 9.0% during the same period [6]. Nevertheless, jump from current level to EAF market share of 37% within next 7 years is hardly possible with respect to existing production infrastructure lifetime, scrap availability and steel quality issues. In this paper to estimate the dynamic EAF market share in global steel production an S-curve was used aiming at 40% in 2050 as shown in Fig.3.

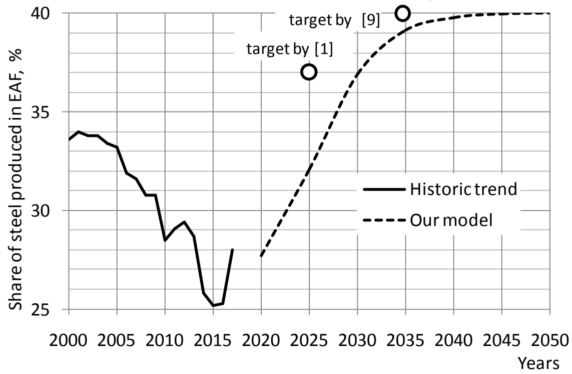


Fig. 3 Share of steel produced in EAF

Scrap load to BOF for individual producers varies in a wide range and scarcely reported (usually 15-30%). Assuming that increased EAF share in steel production will consume most of the scrap available, in our model scrap load to BOF is fixed at 20%. In addition we assume that coal-based DRI will be phased out by 2050 while market share of NG-based DRI will be kept constant.

IEA assumes that in 2050 electricity used for EAFs will be powered by fossil fuels only by 20% compared to 70% in 2011 [1]. Based on this we assume that CO_2 emissions in the EAF will be down by 70% in 2050 from current level thanks to electricity decarbonisation (50%) and BAT deployment (20%). In this paper the scenario representing this assumption is referred to as Available Scrap (Table 1).

2.3.3. CO_2 abatement by deployment of the best available technologies (BAT)

As mentioned above, now at the advanced factories further BAT deployment has very little potential for carbon abatement. However, owing to uneven BAT penetration in different regions, global potential of carbon abatement via BAT remains significant. Recent review by WSA demonstrates that energy intensity of worst 15% blast furnaces is 65% higher than best and energy intensity of worst 15% steel plants is three times higher than best [11].

According to IEA modelling, CO_2 emissions reduction potential achieved through deployment of BAT accounts for 420 $MtCO_2$ per year, representing 19% of CO_2 emissions in the sector [12]. Therefore we optimistically assume that BAT penetration will reach globally 100% by 2050 allowing for 19% CO_2 emissions intensity reduction compared to business as usual. In our model this BAT penetration follows the S-curve with rapid growth start in 2025.

A summary of three non-innovative scenarios is represented in Table 1.

Table 1. Non-innovative scenarios

Scenarios	EAF share, %	Decarbonisation through BAT, %
BAU	25	0
BAT	25	19
Available Scrap	40	19

2.4. CO_2 abatement by deployment of innovative technologies

A number of technologies are developed worldwide, mostly aiming at breakthrough in decarbonisation of ironmaking. In or study we consider several key technologies briefly represented below.

Top Gas Recycling Blast Furnace (TGR BF) concept implies separation of CO_2 from the top gas and injection of remaining gas mixture back into BF - a possibility for new enterprises and for retrofitting. Trials at experimental LKAB BF in Luleo (Sweden) show that recirculation ratio of 90% decreases coke consumption by 25% which corresponds to cutting 24% of CO_2 [13]. However, in such case energy mix of integrated steelwork will be deprived from the BF top gas making this recycling ratio economically unviable. In [14] reduction of CO_2 emissions intensity by 15% with limited top gas recycling ratio is considered as more feasible. Demonstration of TGR was planned in 2015 at ArcelorMittal Florange (France) but suspended owing to financial issues.

Developed in Japan **COURSE50** project aims at CO_2 emission reduction by ca 30 % via cumulative effect of several strategies including use of H_2-amplified coke oven gas for injection to BF, iron ore pre-reduction, TGR, enhancing coke quality for high-H_2 operation, separation and recovery of CO_2 from BF gas using exhaust heat etc. Project completed two R & D stages to schedule, though practical application and diffusion are planned only after 2030 [15].

HIsarna technology combines Cyclone Converter Furnace (CCF) and Smelt Reduction Vessel (SRV). CCF was developed by then Hoogovens company in 1990-s and produces molten partially reduced ore with temperature of 1450°C. SRV backs to HIsmelt technology with demonstration plant of 0.80 Mt/year capacity operated in 2005-2008 in Kwinana (Australia) in collaboration among Rio Tinto, Nucor Corporation, Mitsubishi Corporation and Shougang Corporation. During financial crisis HIsmelt was relocated to China. Currently HIsarna, a hybrid of the CCF and HIsmelt, is developed by Tata Steel in Ijmuiden (The Netherlands) in collaboration with Rio Tinto and some other steelmaking and engineering companies. In 2012-2015 pilot plant (8 t/hour) underwent a series of campaigns reaching 88% of designed productivity in a long term. HIsarna generates more CO_2 than BF but, thanks to phased out cokemaking and sintering, aggregate CO_2 emissions are 20% lower [16]. Demonstration was planned in 2018 with up-scaling and commercialisation after 2020 [17], although no mention to confirm this schedule was found in recent literature.

FINEX is the ironmaking technology developed by South Korean POSCO in collaboration with Siemens VAI based on Corex prototype commercialised in South Africa and India. FINEX substitutes Corex's shaft furnace by a cascade of fluidized bed reactors to heat up and pre-reduce iron ore and applies briquetting machine to enable use of low grade and fine raw materials. In 2003 a demonstration plant (0.6 Mt/year) was erected, followed by launching of the commercial plant (1.5 Mt/year) in 2007 at Pohang Works. More advanced plant (2 Mt/year) with simplified design was launched in 2014. Best result achieved corresponds to 97% of average fuel consumption in BF (combined with cokemaking and agglomeration). It is expected that better process control shall bring this figure down to 90% [18].

In this paper we investigate the effect of decarbonisation of steel production by 10, 20 and 30% for three scenarios as shown in Table 2. These three scenarios are built on top of Available Scrap scenario: i.e. all of them include decarbonisation through BAT by 19% and EAF share of 40% in 2050.

Table 2. Scenarios for innovative technologies commercialisation

Scenarios	Levels of decarbonisation, %			Dynamics of innovative technologies deployment		
				Start year	Rapid growth year	Saturation year
Rapid	10	20	30	2020	2025	2050
Moderate	10	20	30	2025	2030	2050
Delayed	10	20	30	2025	2035	2050
Late	10	20	30	2030	2040	2050

2.5. CO_2 abatement by CCS

The IEA 2DS envisages capturing 40% of the sector's direct CO_2 emissions by 2050 [1]. Two of the options described above – TGR and COURSE50 – employ CCS as part of the technology. In this paper we do not go into details of CCS deployment and just shall mention the following:

- substantial technology progress has yet to be achieved to ensure cost-effectiveness of CCS;
- legal barriers worldwide may hamper large-scale deployment of CCS (e.g. in some EU countries or regions large scale CCS deployment is legally banned [19]).

2.6. Global crude steel production forecast

Comprehensive steel production forecast developed by IEA [1] was published in 2014 and uses 2011 as a baseline. It takes into account a number of factors and offers low and high demand options. As shown in Fig.4 both options essentially deviate below the linear extrapolation of a historic trend. Many other projections for steel demand can be found in literature. One most recent [9] was presented in 2017 and uses 2015 as a baseline, delivering a pathway towards 2035. It is nearly consistent with low demand option of IEA until 2030, but then reduces growth rate with the peak of production reached by the mid-century. Being aware of uncertainties for steel production and consumption forecast, we stick in our study to IEA low demand scenario with emissions intensity pathway derived by Krabbe et al [20].

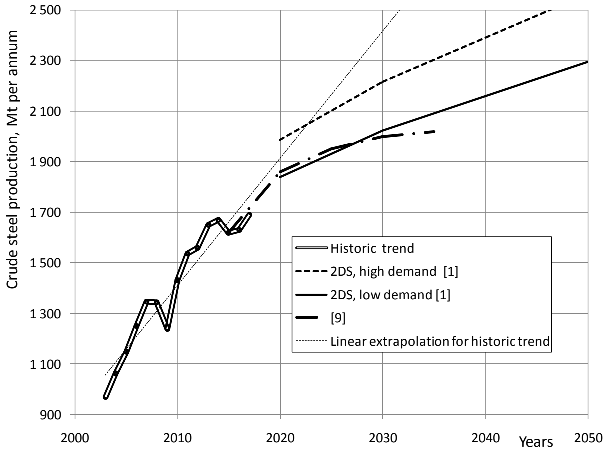


Fig.4 Historic trend and forecast for crude steel production

3. Results and Discussion

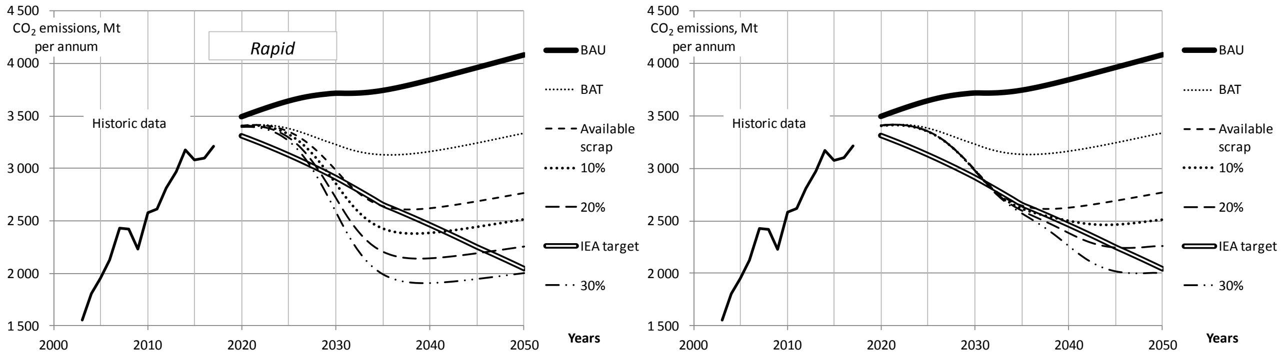
Results of modelling for different scenarios are shown in Fig. 5 (only Rapid and Delayed options are shown for brevity reasons).

In BAU scenario CO_2 emissions continue to grow. Smaller slope compared with historic trend relates to our optimistic choice of a low demand option. Slight bend is caused by S-curved decarbonisation of electricity and phasing out of coal-based DRI.

In contrast to BAU, deployment of BAT allows to decouple emissions from growth through 2035. However, then BAT penetration gradually reaches 100% saturation and emissions continue to grow again.

Availability of scrap followed by increased EAF share changes situation dramatically: emissions are consistent with IEA target from 2031 to 2036. Then, reflecting S-curved penetration model, emissions start to grow again and by the mid-century deviate from IEA target by approximately 0.7 Gt per annum.

Deployment of innovative technologies allows decarbonising production of crude steel with respective depth that is reflected by various levels of dive below the IEA target in three scenarios. Noteworthy, only 30% decarbonisation through innovative technologies can deliver level of emissions consistent with IEA target in 2050. However, even in this scenario emissions will grow above the target after 2050.



a) b)

Fig. 5 Results of modelling for non-innovative and innovative scenario with rapid (a) and delayed (b) deployment of novel technologies (details – in Table 1 and 2)

Aggregate excess amounts of CO_2 emissions for each scenario over the IEA trajectory are shown in Fig.6. Delayed modernisation will require much deeper decarbonisation to keep sectoral emissions within the budget envisaged in IEA scenario, which obviously will increase the total cost of climate change mitigation.

Noteworthy, rapid deployment of innovations with decarbonisation by 10% (maximum that might be enabled by Finex) is not sufficient.

TGR concept has never been demonstrated in an industrial scale, moreover, it involves large scale CCS. Currently, in the world only few CCS projects with off-shore storage have been deployed and few other under development also envisage off-shore storage, whereas many steel factories are located on significant distance from the shore. Moreover, there is no evidence that public acceptance as well as legal aspects will be supportive for large-scale CCS projects and that technology will be cost effective. So, it is difficult to imagine possibility of scenario with active modification of existing blast furnaces into TGR from 2020.

Scenario with moderate pace of deployment of novel technologies with decarbonisation by 20% which will allow to slightly overachieve IEA target might be seen plausible; however, HIsarna, which enables the required decarburization level, has not reached the required technology readiness. Moreover, even if this level will be reached by 2025, existing infrastructure in most of industrialised countries gives little space to ensure necessary dynamics of market penetration. It is more likely, that some countries without robust infrastructure of steel industry will decide to opt for novel reduction-smelting technology (e.g. Myanmar aims to erect factory based on Russian Romelt technology [21]).

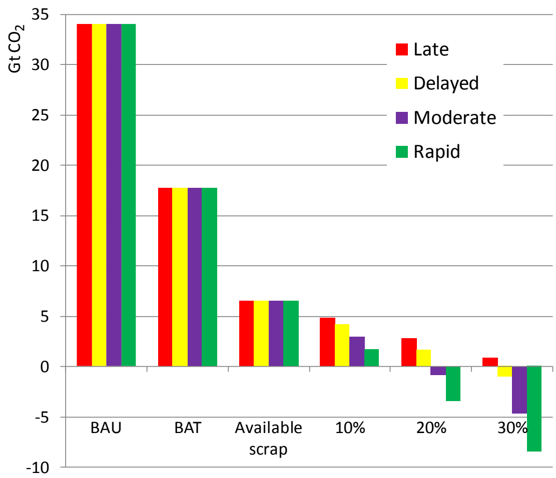


Fig. 6 Amounts of CO_2 emitted in excess to the IEA target during 2020-2050 in various scenarios

The decarbonisation ambition of Course50 would be sufficient to meet climate goals; however, diffusion of the set of technologies being developed in this project is planned only after 2030, moreover, as shown in Fig.6 in the Late scenario even 30% of decarbonisation is - marginally - not enough. It also should be noted that COURSE50 (i) relies on cumulative effect of several technologies, hence if some of them will not work the desirable level of decarbonisation will not be achieved, and (ii) it also employs CCS as part of some technologies and stated above concerns apply here as well.

Some other aspects common to any scenario can be summarised as follows:

1) Currently, even despite huge overcapacity (69.5% capacity utilisation in 2017 and 68.7% in 2018 [6]) erection of new facilities (needless to say retrofitting of existing ones) goes on based on current technologies. Therefore, by the time when deployment of innovative technologies might be considered, too many of steelworks will not reach final depreciation level.

2) Technology transfer can be barred by corporate and national interests. E.g. in our modelling we considered global deployment of COURSE50; however, currently only Japanese participants are involved in its development and funding, so the reasons to share the developed technologies are very conditional.

3) Great potential for deployment of innovative technologies exists in developing countries and industrialised countries with outdated infrastructure (like Ukraine); however, countries of this group are not always able to provide funding. International carbon emissions trading schemes might be helpful, however, taking into account collapse of flexibility mechanisms of Kyoto Protocol, volatility and generally low level of carbon credit prices, certainty of investors into such schemes has yet to be reinforced.

4) In our modelling BAU and consequently the rest of scenarios assume drastic decarbonisation of electricity for EAF and therefore depend upon the success of strategies in power sector.

5) In case if in a reality demand for steel will be higher than considered in 2DS Low Demand, much deeper and faster decarbonisation will be needed.

6) Even in the most optimistic scenarios considered in this study potential of analysed here options for decoupling emissions from production will be explored by mid century, and some other more radically innovative technologies will be needed to ensure consistency with climate change mitigation target beyond 2050.

Conclusions

The window of opportunities to ensure compliance of steel sector development with climate goal still exists though shrinks. Modernisation shall include global deployment of BAT, increased share of secondary steel production and rapid deployment of innovative technologies including CCS. International policies shall be put in place to ensure availability of funding and technology transfer. Short term strategies shall be employed as soon as possible in order to bridge long term projection and current state of the iron and steel industry worldwide.

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